AALTO UNIVERSITY
SCHOOL OF ELECTRICAL ENGINEERING

Department of Electrical Engineering and Automation

Kiran Santhosh

Load Cycling Test and Impulse Test on Low and Medium Voltage Accessories

Thesis submitted for examination for the degree of Master of Science in Technology.

Espoo

Thesis Supervisor:

Professor Matti Lehtonen

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Author: Kiran Santhosh

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Abstract

This thesis has been done for Ensto Finland Oy as a part of expansion of their testing facility. The objective of the project is to study the standards for testing medium voltage and low voltage underground accessories and to determine the requirements for building up the test equipment for heating cycle test and impulse voltage test on them.

Cable accessories to be tested include indoor terminations, outdoor terminations, cable joints and screened separable connectors. Essentially it is required to calculate the ratings of the testing equipment, approximate cost involved (cost information shall only be made available to Ensto Finland Oy and not discussed here) and required space for setting up the testing station.

Tests were carried out to calculate the required rating of heating cycle test transformers. Safety standard for test laboratories were also studied in order to estimate space requirement and procedure for the safe installation and operation of the test equipment. Offers from various manufactures were collected to obtain the approximate cost for the test equipment.

Keywords: Heating cycle voltage test, Load cycling, Cable testing, Impulse voltage testing, Cable accessory testing.

Preface

This thesis is submitted in partial fulfilment of the requirements for Master’s Degree, in Power System and High Voltage engineering from Aalto University, School of Electrical Engineering. This thesis was carried out during the period of January 2013 to January 2014.

I would like to express my sincere gratitude to Janne Lappalainen, for giving the opportunity to do my Master’s thesis at Ensto Finland Oy and for his assistance and guidance with regarding to the thesis. I appreciate the support and encouragement of Prof. Matti Lehtonen during my research. I would like to thank my instructor Jukka Mäkeläinen and my colleagues Arne Liljeström, Kenneth Väkeväinen, Kauko Alkila, Kari Malinen for all the technical support and encouragement they gave me. I thank Petri Hyvönen Head of Laboratory and Joni Klüss researcher, for all the technical assistance they have given especially in the beginning of my thesis.

I would like to extend my sincerest thanks to Jan Thorén of Thorén engineering and Csaba Homok of Veiki-VNL high voltage laboratories for their valuable input for my thesis. Without their help it would have been exceedingly difficult to complete my thesis.

I am also grateful to Juha, Lea, Sabin, Devi, Andrea, Michael, Irina and all other friends in the University. Finally I wish to thank my parents Indira and Santhosh, my sister Kavya my cousin Nithil, sister in law Priyanka for their love and support throughout my studies.

Espoo, December 29, 2013

Kiran Santhosh

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List of symbols

C	Capacitance
f	Frequency
I_A	Current obtained from method A
I_B	Current obtained from method B
I_C	Current obtained from method C
I_c	Capacitive current
l_{cal}	Heating current under calibration
l_{test}	Heating current under testing
k_t	Temperature correction factor
L	Length of the cable
R_t	Measured conductor resistance
R_{20}	Resistance per unit length of conductor at 20 °C
T'	Thermal resistance between the conductor and the external surface of cable
V	Test voltage

α_{20}	Temperature coefficient of resistance at 20 °C
$\theta_{amb.c}$	Ambient temperature
θ_{cond}	Conductor temperature
$\theta_{sheath.c}$	Sheath temperature
$\theta_{sheath.t}$	Sheath temperature at test condition

List of abbreviations

EPR	Ethylene propylene rubber
HEPR	High module ethylene propylene rubber
PVC	Polyvinyl chloride
XLPE	Cross-linked polyethylene

1 Introduction

1.1 Objective

The objective of the project is to study the standards for testing medium voltage and low voltage underground accessories and to determine the requirements for building up the test setup for heating cycle test and impulse voltage test. Cable accessories to be tested include indoor terminations, outdoor terminations, cable joints and screened separable connectors. Essentially it is required to calculate the capacity of testing equipment required, approximate cost involved (cost information shall only be made available to Ensto Finland Oy and not discussed here) and required space for setting up the testing station. In order to determine the rating of test the equipment, maximum cable cross-section for which Ensto Finland Oy’s product is available is chosen. For the impulse test it is desired to test accessories beyond the standard requirement for experimental purposes, so the ratings of the equipments are chosen accordingly. This thesis mainly concentrates on medium voltage accessories.

1.2 Motivation behind the project

Ensto Finland Oy has a comprehensive testing facility for testing their own underground and over headline products; however the testing capacity for underground products are limited when compared to the over headline ones. In order to improve and expand the testing possibilities for the underground products it was decided that new heat cycling and impulse testing devices shall be purchased.

Heating cycle test is one of the most critical tests among the type tests. Since it is a long duration test, it would be good to carry out preliminary heating cycle test at Ensto Finland Oy's facility before the actual type tests can be started at a certified laboratory. Heating cycle test gives an indication of the performance of the tested accessories over time. Impulse test is carried out on the test sample to see if the accessories withstand lightning impulse voltages. Since this test is one of the type tests, and results from the tests are obtained immediately unlike the heating cycle test, it can be used as preliminary test to determine if the accessory under test is capable of passing the type tests or not.

Previously heating cycle and impulse voltage withstand tests for Ensto Finland Oy's accessories were carried out in testing facilities outside of Finland, which makes it difficult for the product designers to have immediate access to the test results and the test samples after the test. A viable solution for these problems would be to do these tests in-house.

The product development section of Ensto Finland Oy is constantly developing products for underground products. These required to be tested to ensure that they fulfil the standard requirement. With the ability to test some of the essential tests in-house product development time can be considerably reduced. In addition to this, exiting products could be tested for quality control and claim handling also.

2. Heating cycle voltage test for medium voltage accessories

One of the main modes of failure in cables and associated accessories is thermal failure, thus the thermal behaviour of cable systems is a very important aspect in the design of cable accessories and can be evaluated by heating cycle (load cycling) tests. The cable with all the accessories to be tested is heated up by passing enough current so that the temperature of the cable rises to a specific value determined by the insulation material of the cable. This temperature is maintained for a specified time and after that the cable is allowed to be cooled close to ambient temperature. One heating and cooling sequence constitutes one cycle; such cycles are repeated for the specified number of times, depending on the type of accessory. The test cable shall be under voltage for the entire duration of the test and this voltage is normally more than the nominal voltage of the cable. Depending upon the type of accessory the test can be conducted either in dry or wet conditions.

According to IEC 61442 the duration of a single cycle should be at least 8 hours with a minimum natural cooling time of 3 hours. The final temperature of the cable should be within +10K range of the ambient temperature. It is also essential to maintain not less than 2 hours of steady temperature during the test. It is considered that stabilization has been reached if the conductor temperature does not show any variation larger than 2 K within a 2 hour period [1].

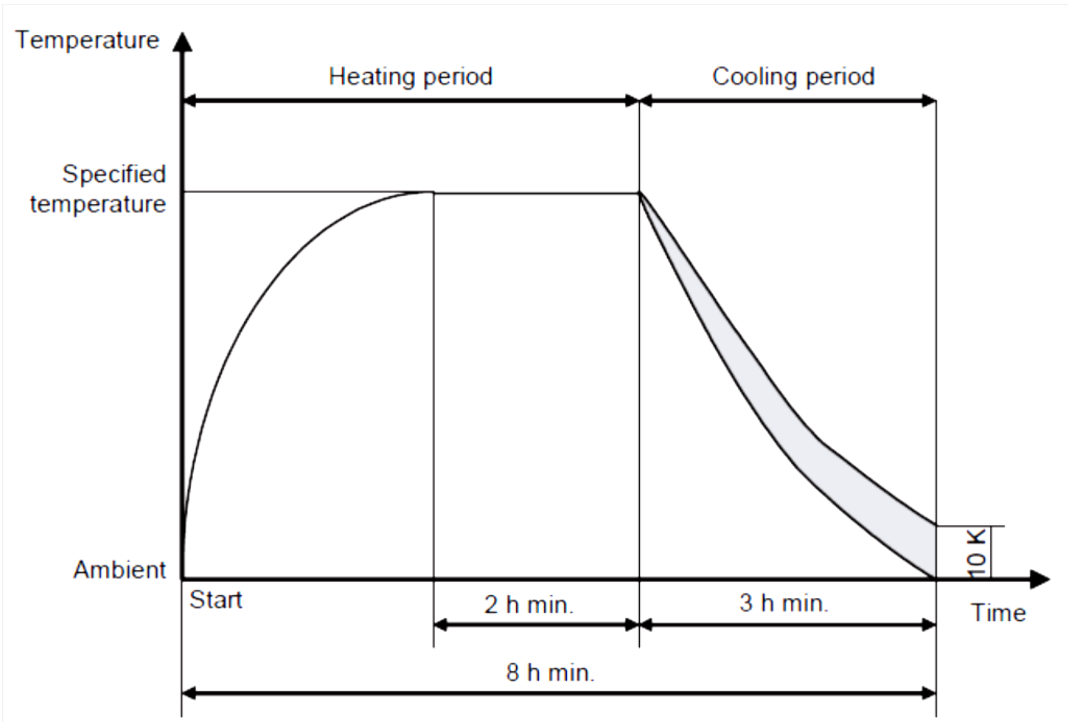


Fig. 2.1 - Typical heat cycle [1]

2.1 General conditions and guidelines for the test and installation [1]

1) Cables used for testing shall comply with HD 620 standard.
2) Connectors used within the accessory shall comply with EN 61238-1.
3) For transition joints, the testing parameters such as the voltage and the conductor temperature are those for the lower rated cable.
4) Cable screens, and armour if any, shall be connected together and earthed at one end only to prevent circulating currents.
5) All parts of an accessory which are required to be at ground potential shall be connected to the cable screen. Any supporting metalwork shall also be earthed.
6) Ambient temperature shall be 20 ± 15 °C.
7) Tap water shall be used for all tests in water.
8) Accessories are installed as per the manufacturer’s instruction. Terminations are usually installed in vertical orientation unless the installation guide specifies a different orientation. The spacing between the terminations shall be maintained as given in the installation manual.
9) Lugs used for making electrical connections shall have electrical cross-section equivalent to that of the cable conductor used for testing.
10) If the cable accessory to be tested is a branch joint, only the main cable shall carry the heating current.
11) For cables with non-longitudinally water-block design oversheath damage is required. An annulus of oversheath of at least 50 mm length is removed from the cable at a point beneath water level and 50 mm to 150 mm from the exterior portion of the joint.
12) The test under water is not required for joints with a continuous metallic covering plumbed or welded to the cable metallic sheath.
13) Connectors used in the joints shall have their specification marked on them. They shall also have information on the range of conductor cross-section that it supports.
14) Tests on separable connectors shall be performed with separable connector installed on its mating bushing.
15) Unless otherwise specified conductor cross-section shall be for terminations and joints; 120 mm^2 or 150 mm^2 or 185 mm^2. This is valid for accessories made for cable cross-sections between 95 mm^2 and 300 mm^2 .For separable connectors cross-section shall be as indicated in table 2.1, with either copper or aluminium conductors.
16) The tests shall be started within 24 h after the installation of the accessories on the test cable, unless otherwise specified by the manufacturer. In which case the time interval between the finishing of installation and the commencement of test shall be noted.

Rating of separable connector [A]	Cable conductor cross-section [mm^2]	
	Cu	Al
250	50	70
400	95	150
630	185	300
800	300	400
1250	500	630
Note: The use of above mentioned cross-sections may lead to overheating of the bushings while achieving the required conductor temperature. In this situation it is possible to use a conductor one size smaller. If bushing failure occurs tests shall be declared void.		

Table 2.1 - Test conductor cross-sections for separable connectors [1]

2.1.1 Test Voltages [3]

Test voltage used for heating cycle test shall be an alternating voltage with frequency ranging from 45 Hz to 65 Hz. Shape of the waveform shall be approximately sinusoidal with the difference of the magnitudes of the positive and negative peak values being less than 2 %. The test voltage shall be maintained within ±3 % of the specified test voltage level throughout the test.

The voltage source shall be able to provide a stable output voltage so that the measured output voltage remains within ±3 % of the specified level throughout the test irrespective of leakage current. The test voltages according to IEC61442 are given in the following table.

	Rated voltage U_0\U (U_m) kV									
	3,6/6(7,2)	3,8/6,6(7,2)	6/10(12)	6,35/11(12)	8,7/15(17,5)	12/20(24)	12,7/22(24)	18/30(36)	19/33(36)	20,8/36(42)
Test voltage $2{,}5U_0$	9	9,5	15	16	23	30	32	45	47,5	52

Table 2.2 - Test voltages [2]

2.1.2 Test Currents [1]

The test current should be sufficient enough to raise the temperature of the cable to the desired level. This temperature is 5 K to 10 K above the maximum cable conductor temperature in normal operation for extruded insulation cables and 0 K to 5 K above the maximum cable conductor temperature in normal operation for paper insulated cables.

2.2 Test specifications

Test arrangement and number of samples required per test sequence are demonstrated in the figures given below.

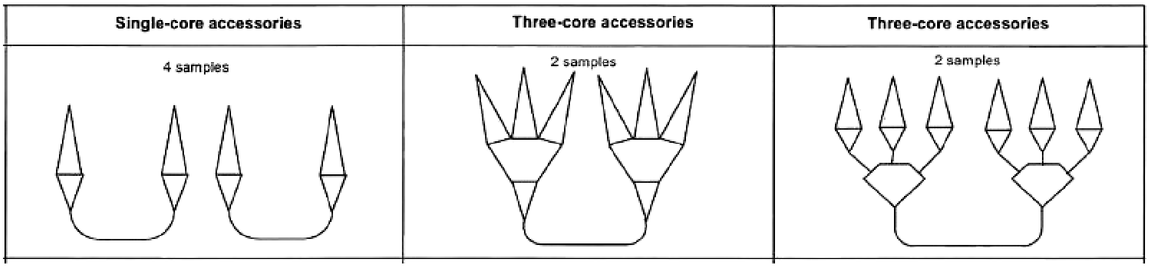


Fig. 2.2 - Test arrangement for indoor and outdoor terminations [2]

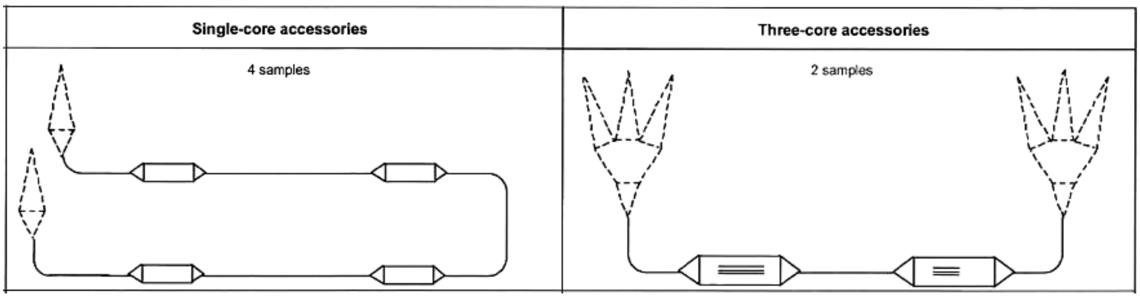


Fig. 2.3 - Test arrangement for joints [2]

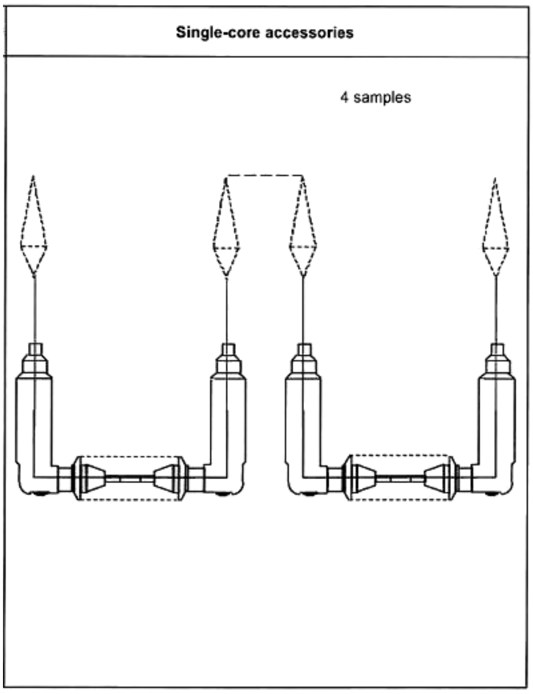


Fig. 2.4 - Test arrangement for screened separable connectors [2]

Number of cycles and test requirements are given in the table below.

Accessory	Test	No of cycles	Test voltage	Requirement
Indoor termination for extruded insulation cables	Heating cycle voltage test in air	126	$2.5U_0$	No breakdown or flashover
Outdoor termination for extruded insulation cables	Heating cycle voltage test in air	126	$2.5U_0$	No breakdown
	Immersion	10	-	-
Joints for extruded insulation cables	Heating cycle voltage test in air	63	$2.5U_0$	No breakdown
	Heating cycle voltage test in water	63	$2.5U_0$	No breakdown
Screened separable connectors for extruded insulation cables	Heating cycle voltage test in air	63	$2.5U_0$	No breakdown
	Heating cycle voltage test in water	63	$2.5U_0$	No breakdown
Additional tests for non-circular conductor profile and/or insulation screen profile compliance	Heating cycle voltage test in air	126	$2.5U_0$	No breakdown or flashover
Additional tests for smallest and largest cable cross-section compliance	Heating cycle voltage test in air	10	$2.5U_0$	No breakdown or flashover

Table 2.3 - Test specification [2]

2.3 Preparation of Cable

Cable accessories are installed as per installation instructions given by the manufacturer. The package containing the accessories has an installation manual giving guidance to how to install the accessories correctly. There is also information in Ensto Finland Oy's website regarding the cable accesory installation. Thermocouples are used for measurement of temperature measurement. They shall be attached to the cable sheath at specific positions as shown in Figures 5 to 10. Theses sheath temperatures can be used as a reference for measuring conductor temperature. Instruction for installing thermocouple is given in temperature measurement section. When only cable lugs are used for making electrical connection sufficient length of semiconductor layer from the cable shall be removed so that there is no flashover from cable lug to the semi conductor layer. It is also possible to test cable terminations and cable joint simultaneously.

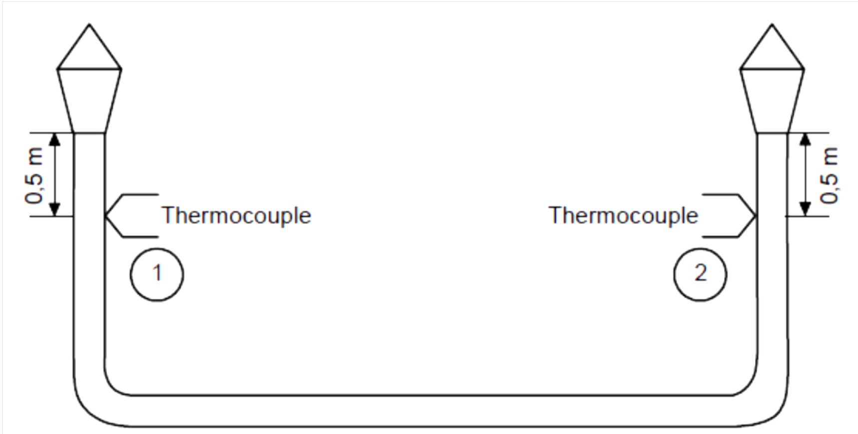


Fig. 2.5 - Terminations tested in air [1]

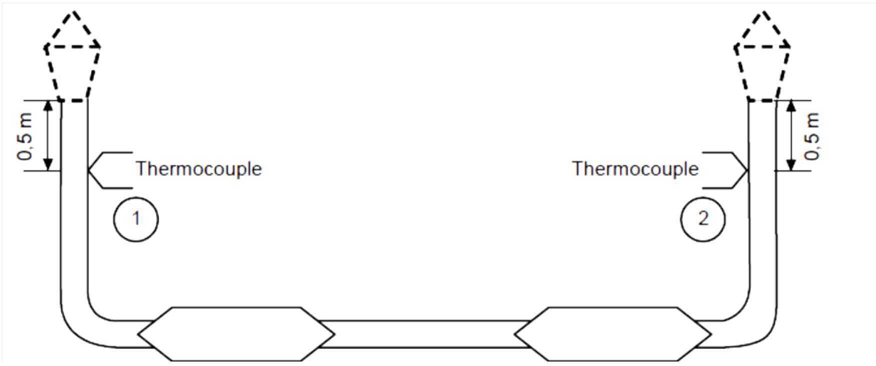


Fig. 2.6 - Joints tested in air [1]

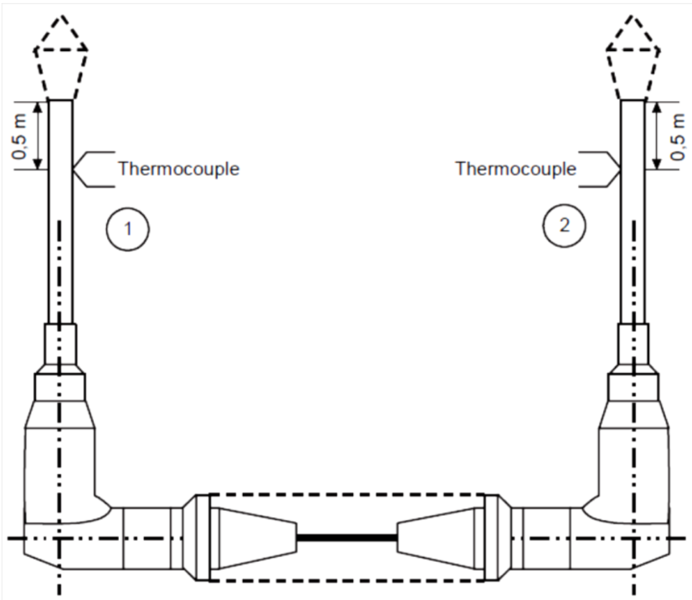


Fig. 2.7 - Separable connectors tested in air [1]

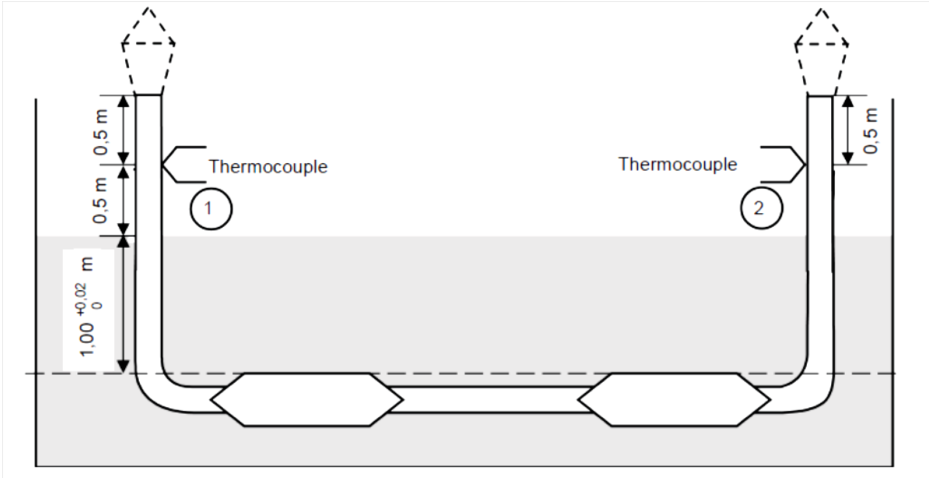


Fig. 2.8 - Joints tested under water [1]

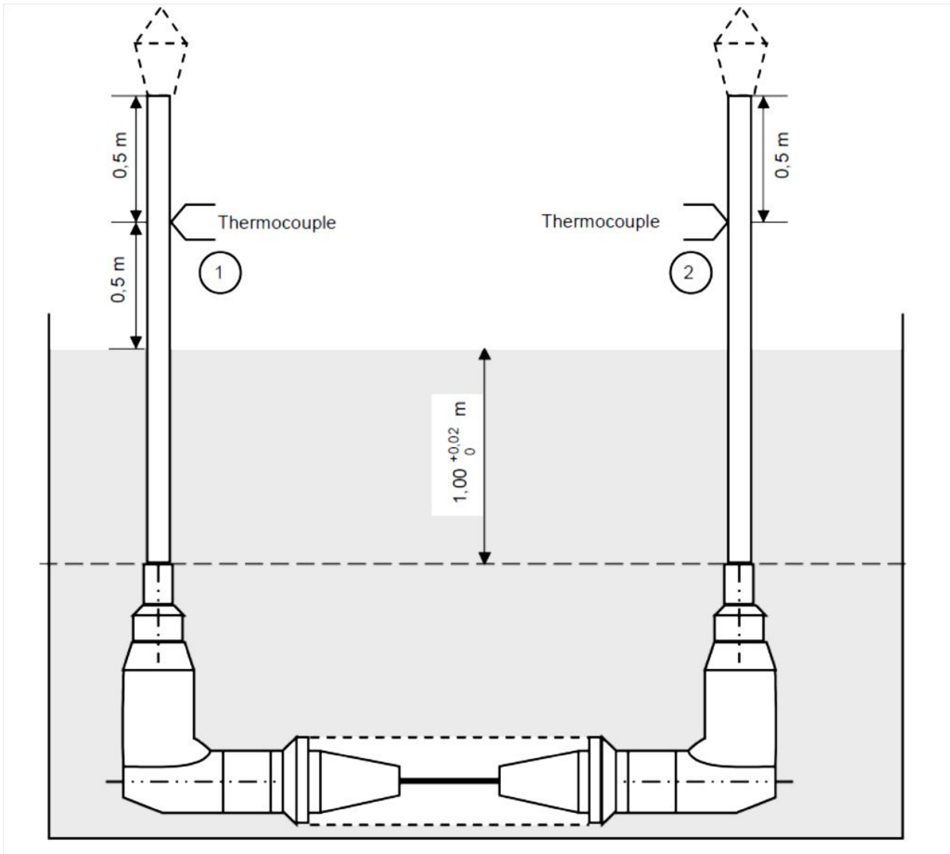


Fig. 2.9 - Separable connectors tested under water [1]

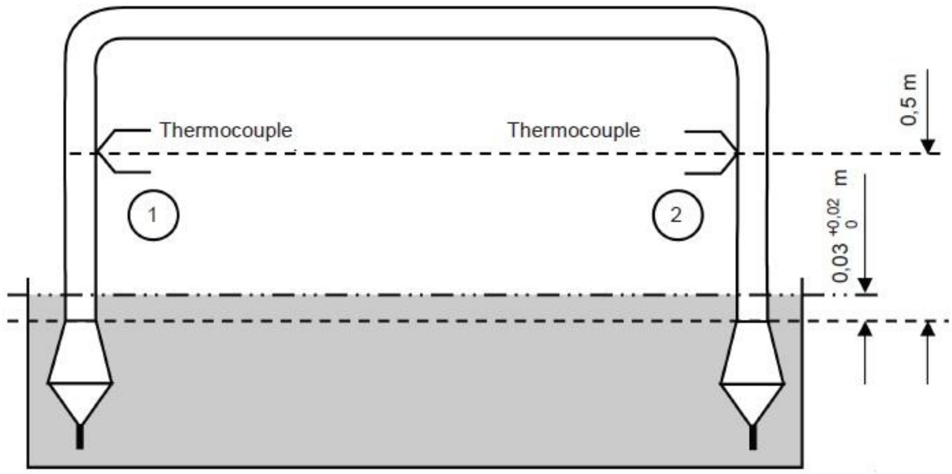


Fig. 2.10 - Outdoor terminations tested under water [1]

Cable prepared as per above diagrams can be mounted inside a water tank of dimension 4mx1mx1.5m for both wet and dry test. This dimension would be enough to accommodate the cable inside the tank. However the water height of 1,0 m might not be sufficient in special applications and in situations subject to a high water table or prone to flooding. In such situations manufacturer and the customer can agree upon an increased water height of 20m [1]. So tank having more depth shall be required to meet this requirement; however I shall not be discussing such a scenario in this document. It should also be noted that using a particular water height gives only compliance up to that pressure. If cable and accessories are tested at both 1m and 20m water height compliance is given for both the pressures and al the intermediate pressures.

2.4 Temperature measurement

Since the cable and accessories under test would be energized it is not possible to measure the conductor temperature directly. Thus, it is necessary to carry out a preliminary calibration on the test cable to determine the actual conductor temperature during the accessory tests, allowing for the permitted variation in ambient temperature. IEC 61442 suggests three methods to accomplish this. Convenient way to do this would be calibrate the test cable based on measurement of the external surface temperature (sheath temperature). Procedure for installation of thermocouple and calibration is given below. Other methods of calibration shall not be discussed here.

2.4.1 Installation of thermocouples

Thermocouples are used for the measurement of temperature. These are installed at least 0,5 m from both ends of the cable. The cable used for calibration shall be at least 2 m long. Thermocouples are installed both on the conductor and on the external surface. Figures 2.11 and 2.12 shows how the thermocouples are installed on the cable.

The thermocouples shall be secured to the cable so that it does not come off due to the vibration of the cable during the heating cycle. To attach the thermocouple on to the sheath, first a layer of copper tape is applied and then on top of that two additional half lapped layer of adhesive tape is also applied [1]. To measure the conductor temperature thermocouple should be in contact with conductor for this purpose a hole is drilled into the cable till the conductor. This hole shall have a diameter between 1 mm to 2 mm [1]. Thermo couple shall be carefully inserted into the hole and it shall be made sure that the thermocouple is in contact with the conductor.

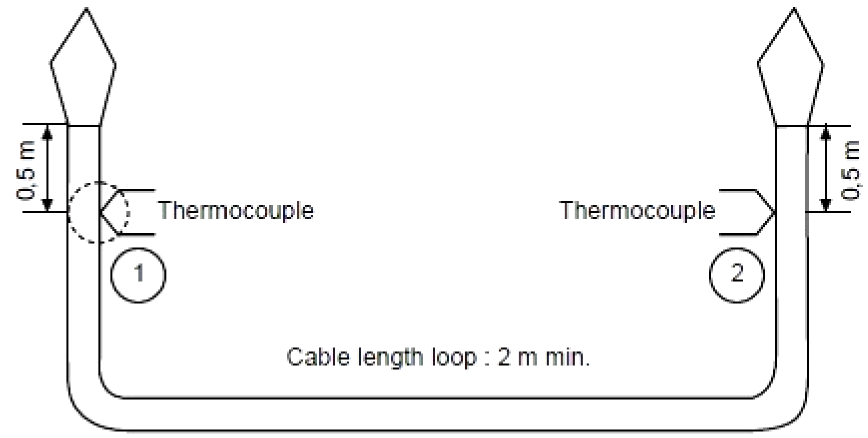


Fig. 2.11 - Reference cable [1]

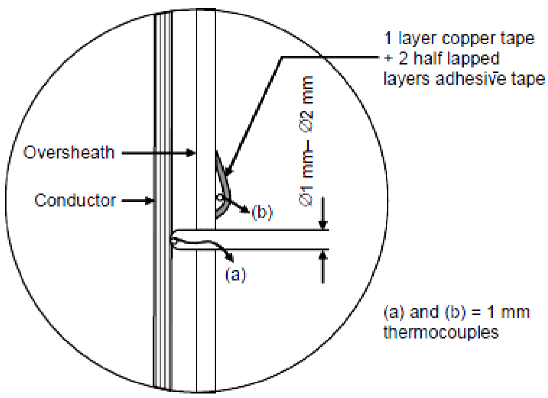


Fig. 2.12 - Arrangement of the thermocouples [1]

2.4.2 Calibration based on measurement of external temperature [1]

The calibration should be carried out in a draft-free situation at an ambient temperature of 20±15 °C. Conductor, sheath and ambient temperatures shall be monitored and recorded. The cable should be heated until the conductor temperatures a1 and a2, indicated by thermocouples (a) at positions 1 and 2 of Fig. 2.11, have stabilized and reached the temperatures given below:

a) Between 5 K and 10 K above the maximum conductor temperature of the cable in normal operation.
b) Between 0 K and 5 K above the maximum conductor temperature of the cable in normal operation.

Nominal temperatures for various insulation types are mentioned in table 3.1. It is considered that stabilization has been reached if the conductor temperatures, a1 and a2, do not show any variation larger than 2 K within a 2 h period.

When stabilization has been reached, the following should be noted:

a) Conductor temperature $\theta_{cond} = \frac{(a_1 + a_2)}{2}$
b) Sheath temperature $\theta_{sheath.c} = \frac{(b_1 + b_2)}{2}$
c) Heating current l_{cal}

We have during calibration:

$$\theta_{cond} - \theta_{sheath.c} = R_{20} \times I^2_{cal}\,[1 + \alpha_{20}\,(\theta_{cond} - 20)]T' \text{------- } 2.1$$

We have during the test:

$$\theta_{cond} - \theta_{sheath.t} = R_{20} \times I^2_{test}\,[1 + \alpha_{20}\,(\theta_{cond} - 20)]T' \text{------- } 2.2$$

We have following results from above equations.

The test current value l_{test} required during the actual test

$$l_{test} = l_{cal}\sqrt{\frac{\theta cond - \theta sheath.t}{\theta cond - \theta sheath.c}}$$

The conductor temperature θ_{cond} can be found out from following equation.

$$\theta_{cond} = \frac{\theta_{sheath}.t + (1 - 20\alpha_{20})R_{20}\, I^2_{test}\, T'}{1 - \alpha_{20} R_{20}\, I^2_{test}\, T'}$$

$\theta_{sheath.t}$ is sheath temperature at test condition
α_{20} is the temperature coefficient of resistance at 20 °C
R_{20} is the resistance per unit length of conductor at 20 °C
T' is the thermal resistance between the conductor and the external surface of cable
T' can be found out from equation 2.1

α_{20} and R_{20} can be found according to IEC 60228 as follows.

In order to calculate R_{20} DC resistance of the conductor has to be measured first. For this purpose a sample cable of length at least 1 meter is used. Resistance measurement shall be conducted at room temperature and the temperature shall also be noted. Convert the resistance measured to resistance per kilometre. This calculated value can be directly used in the equation below to calculate R_{20}

$$R_{20} = R_t \times k_t \times \frac{1000}{L}$$

k_t is the temperature correction factor from Table 2.4
R_{20} is the conductor resistance at 20 °C, in Ω/km
R_t is the measured conductor resistance, in Ω
L is the length of the cable, in m
α_{20} is 0,004 per K at 20 °C

Temperature of conductor at time of measurement t °C	Correction factor, k_t All conductors	Temperature of conductor at time of measurement t °C	Correction factor, k_t All conductors
0	1,087	21	0,996
1	1,082	22	0,992
2	1,078	23	0,988
3	1,073	24	0,984
4	1,068	25	0,980
5	1,064	26	0,977
6	1,059	27	0,973
7	1,055	28	0,969
8	1,050	29	0,965
9	1,046	30	0,962
10	1,042	31	0,958
11	1,037	32	0,954
12	1,033	33	0,951
13	1,029	34	0,947
14	1,025	35	0,943
15	1,020	36	0,940
16	1,016	37	0,936
17	1,012	38	0,933
18	1,008	39	0,929
19	1,004	40	0,926
20	1,000		

Table 2.4 - Correction factor values for different conductor temperatures [4]

The values of temperature correction factors specified are approximate but give practical values well within the accuracy that can normally be achieved in the measurements of conductor temperature. This accuracy level is enough for our test purposes. If the test is not automatically controlled it is advisable to plot a graph between θ_{cond} and $\theta_{\text{sheath.t}}$ for different values of I_{test} from the equations of θ_{cond}. Sample graph is shown in Fig. 2.13.

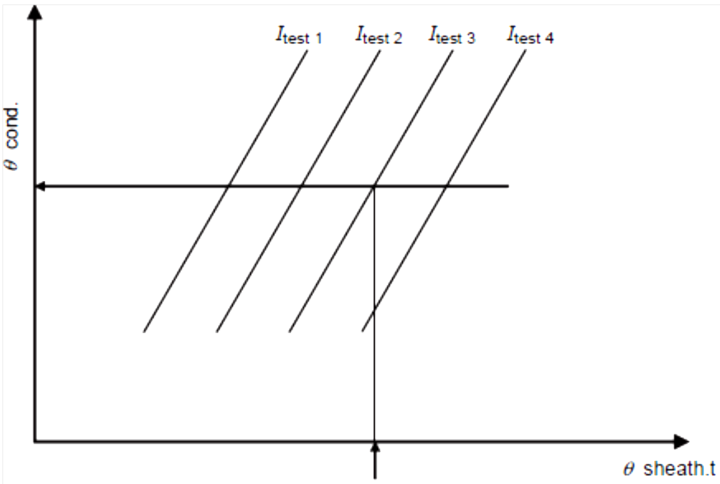


Fig. 2.13 – Current V/S temperature curves [1]

2.5 Range of compliance [2]

For terminations and joints made for cable with cross-sections between 95 mm^2 to 300 mm^2 compliance with IEC61442 heat cycle voltage test can be obtained by successfully completing all the appropriate tests on 120 mm^2 or 150 mm^2 or 185 mm^2 cross-sections.

For separable connectors, compliance with IEC61442 heat cycle voltage test for the range of cable conductor cross-sections given in table 2.5 shall be obtained by successfully completing all the appropriate tests on the cross-section specified in table 2.5.

Rating of separable connector [A]	Cable conductor cross-section range of compliance [mm^2]	
	Min	Max
250	25	95
400	95	240
630	95	300
800	150	400
1250	240	630

Table 2.5 – Range of compliance of separable connectors [2]

Compliance can be obtained for larger or smaller cross-section by completing the additional test sequence, on the appropriate larger or smaller cross-section. For extension of compliance of separable connectors to larger cable conductor cross-sections, the test current shall be limited to the rating of the mating bushing. Compliance shall extend to the use of an accessory on cables of the same nominal voltage as the test cable but with greater nominal insulation thickness, however the converse shall not apply.

If the cable accessory under test has minimum or maximum cross-section, that does not fall between 95 mm^2 to 300 mm^2 the client and the manufacturer can decide which cross-section to use. Tests can be carried out with aluminum or copper conductors. Testing with one material automatically gives compliance with the other one.

If compliance has to be obtained among different shapes of conductors aadditional tests for non-circular conductor profile and/or insulation screen profile compliance test sequence can be carried out for whichever conductor shape for which compliance is required.

Compliance is dependent on the cable insulation as detailed in Table below.

Test cable insulation	Range of compliance
XLPE	XLPE, EPR, HEPR, PVC
EPR or HEPR	EPR, HEPR, PVC

Table 2.6 – Range of insulation compliance [2]

Compliance for accessories tested on cables with one type of insulation screen may be extended to another type of insulation screen by satisfactory completion of additional tests for non-circular conductor profile and/or insulation screen profile compliance test sequence.

Compliance obtained by testing on a cable without longitudinal water-blocking in the metallic screen area shall be extended to a cable with means of longitudinal water-blocking in the metallic screen area but otherwise of the same design. However he converse shall not apply.

Compliance obtained for a three-core accessory shall extend to a single-core accessory provided they have the same design, however converse shall not apply. Compliance of an accessory tested for a specified nominal voltage shall extend to operation of the accessory at a lower nominal voltage provided that the radial electrical stress at the insulation screen of the cable of lower nominal voltage is not greater than that of the test cable.

2.6 Test results

2.6.1 Test reports [2]

Test report shall clearly mention the test arrangement and test procedure applied to carry out the test. There shall be data provided on the technical specification of the product under test. Construction details of the test cable including conductor type, insulation type, conductor diameter, type of screen, type of armour etc shall be mentioned in the test report. The test report shall be signed by the personnel who is responsible the test as well as the representative of the test facility. In the case of Ensto Finland Oy the representative is the laboratory manager.

2.6.2 Failures [2]

All the test samples are not of equal quality so there is a chance that a faulty or a substandard sample was used for test. In such a situation the faulty sample shall be dismantled and inspected to establish the cause of failure. It is not required to mention about this in the report.

If an accessory fails to meet the requirements due to either installation or test procedure errors, the test shall be declared void without discrediting the accessory. The complete test sequence may be repeated on a new set of samples.

If a bushing failure occurs, the test shall be declared void without discrediting the accessory. Tests may be repeated using new bushings, starting from the beginning of the test sequence.

If the cable fails beyond any part of the accessory, the test shall be declared void without discrediting the accessory. Tests may be repeated using a new accessory and start from the beginning. Alternatively the cable can be repaired and test can be resumed whence it failed.

If any failure happens other than mentioned above then the product has failed the test. A design change or a material change might be required before the type test can be started again.

3. Heating cycle test for low voltage accessories

The heating cycle test simulated stresses experienced by the cable accessories under service condition within a short period of time. EN 50393 describes the test conditions and test procedures for test methods and requirements for accessories for use on distribution cables of rated voltage 0,6/1,0 (1,2) kV. Duration of one cycle including the heating and cooling is limited only to 8 hours and the test object is also not energized unlike IEC 61442. A typical heating cycle is given below. Heating cycle test is carried out in water as well as air depending upon the accessory under test.

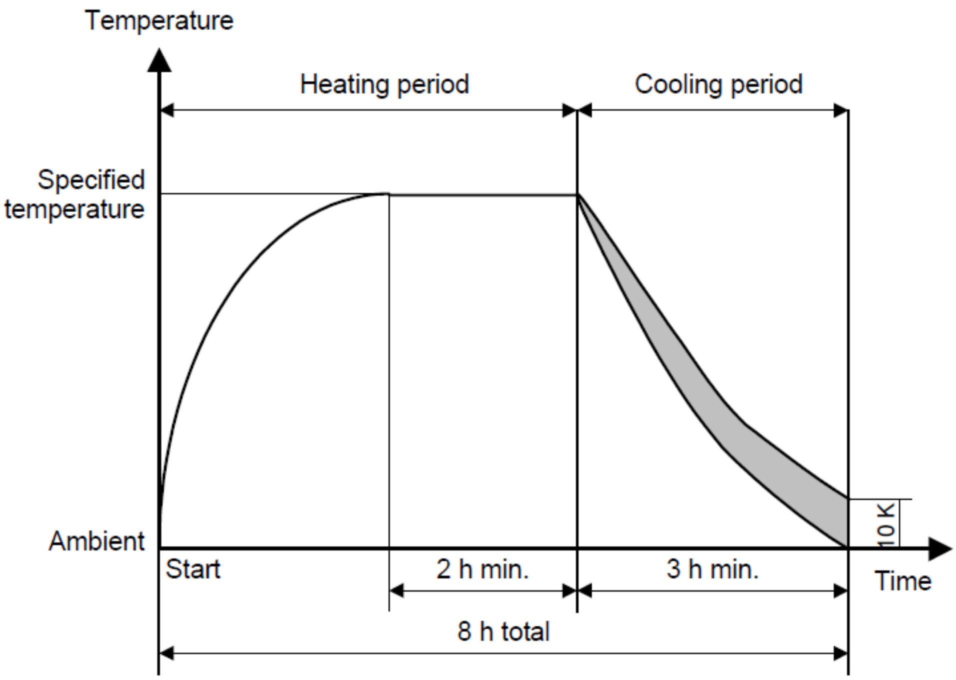


Fig. 3.1 - Typical heating cycle [5]

3.1 General guidelines for test condition and test samples [5]

1) Tests shall be made at an ambient temperature within the range 20 ± 15 °C
2) Tap water shall be used for all tests in water.
3) The tests shall be started within 24 h after the installation of the accessories on the test cable, unless otherwise specified by the manufacturer. In which case the time interval between the finishing of installation and the commencement of test shall be noted.
4) Cable screen and amour, if any, shall be bonded and earthed at one end only to prevent circulating currents.

5) Accessories shall be dry and clean, but neither the cable nor the accessories shall be subjected to any form of conditioning which may modify the electrical, thermal or mechanical performance of the test assemblies.
6) Cables used for testing shall comply with HD 603.
7) Accessories shall be assembled in the manner specified in the manufacturer's instructions, using the components supplied in the kit.
8) The connectors used in a joint or termination shall comply with IEC 61238-1.
9) During the heating cycle in water the temperature of the water shall be 20 ± 15 °C.

3.2 Test installation and temperature measurement

All the accessories are installed as per manufacturer's instruction. Temperature measurement is carried out as given in section 2.4 and calibration of test cable is done as given in section 2.4.2. For the test in air thermocouple shall be attached to the sheath at least 1 meter away from the accessory under test [5]. For test in water the thermocouple shall be placed minimum 0,5 meter above the water level. In both the cases the thermocouple shall be placed at least 0,5 from the external crutch [5]. Test arrangements for various accessories are given below. Conductor temperatures shall be recorded during each cycle. Any cycle during which the specified minimum conductor temperature is not reached additional cycles are carried out to achieve the specified number. Figures 3.2 to 3.4 gives the various configurations used for different accessories. Height h= 1000+20 mm for Fig 3.3 and for Fig 3.4 it is equal to 300 ± 100 mm.

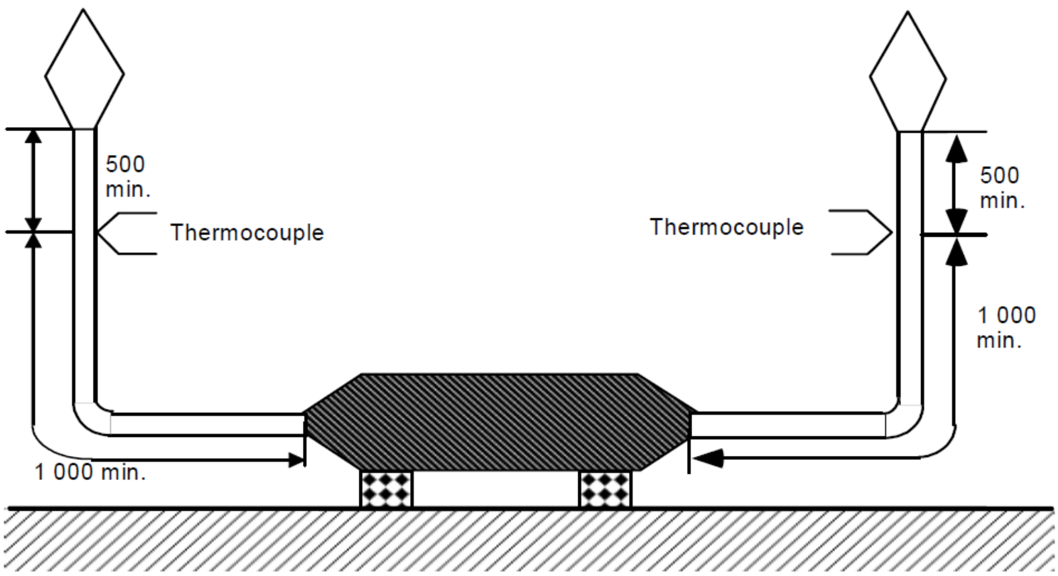


Fig. 3.2 - Typical arrangement for the heating cycle in air [5]

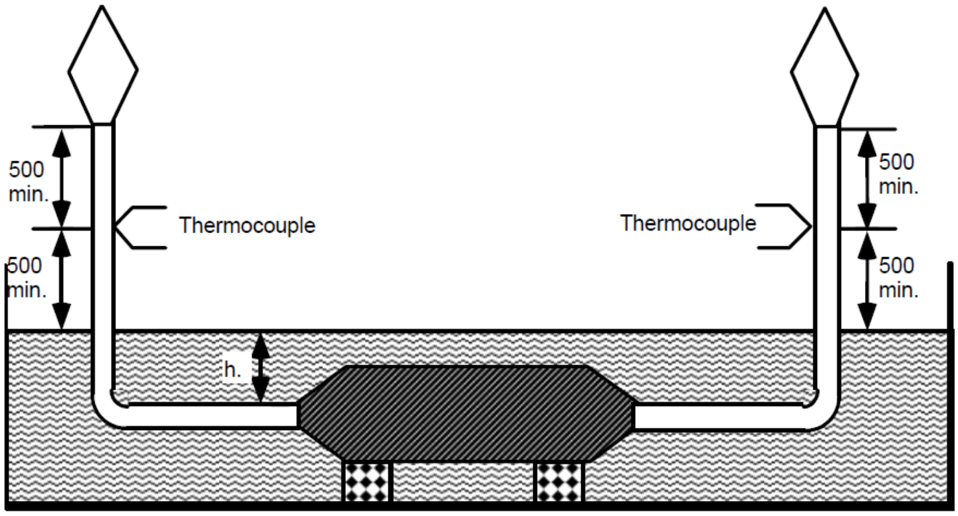


Fig. 3.3 - Typical arrangement for the heating cycle for joints in water [5]

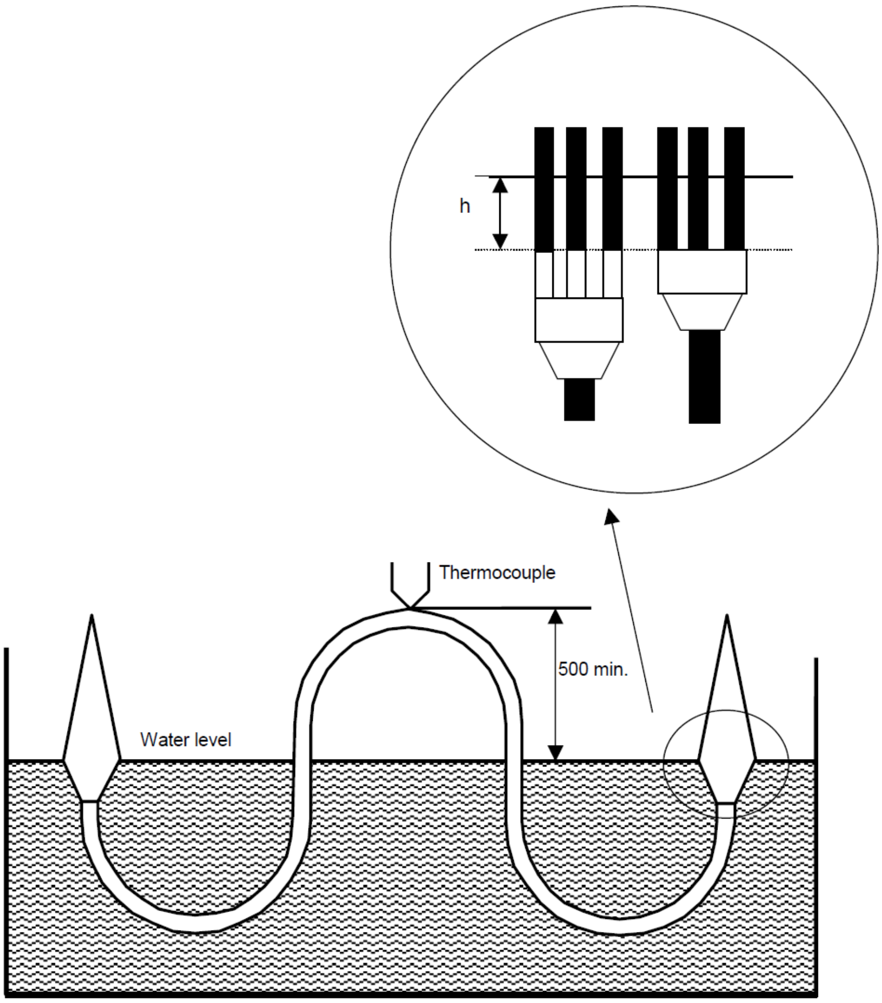


Fig. 3.4 - Typical arrangement for the heating cycle for outdoor terminations in water [5]

3.3 Test procedure

The temperature of the main conductors and branch conductors when the area of cross-section is more than 50 mm² shall be raised to between 5 K and 10 K of the normal operation temperature of the test cable during the heating cycle test [5]. The current source shall have adequate rating to provide the required amount of current to achieve this condition. The normal operational temperature for various insulation materials are given below.

Insulation type	Temperature ºC
Impregnated paper	80
PVC Insulation	70
XLPE Insulation	90
EPR Insulation	90
HEPR Insulation	90

Table 3.1 - Normal operational temperature for different insulations [6]

3.3.1 Test in air [5]

The temperature of the main conductors and branch conductors if its cross-section is greater than 50 mm² shall be raised to between 5 K and 10 K above the maximum rated temperature. The test configurations for various accessories are shown in figures 3.5 to 3.8. A steady conductor temperature shall be maintained for not less than 2 hours. After the 2 hours minimum steady temperature period the current shall be switched off and the cable allowed to cool naturally to within 10 K of ambient within a period not less than 3 hours.

3.3.2 Test in water

3.3.2.1 Joints [5]

For cables with non-longitudinally water-block design oversheath damage is required. An annulus of oversheath of at least 50 mm length is removed from the cable at a point beneath water level and 50 mm to 150 mm from the exterior portion of the joint. The assembly shall be placed in a water bath so that the cable is 1000+20 mm below water level. A different water height can be used in some special cases which will be discussed later in section 3.5. The oversheath damage requirement does not apply to non water-blocked cable designs. Temperature conditions are the same as for test in air.

3.3.2.2 Outdoor terminations [5]

The thermocouple shall be placed as shown in Fig. 3.4. The water height over the crutch shall be h = 300 ± 100 mm. Temperature conditions are the same as for test in air.

3.3.3 Test configurations [5]

Test arrangements for all the accessories are shown below.

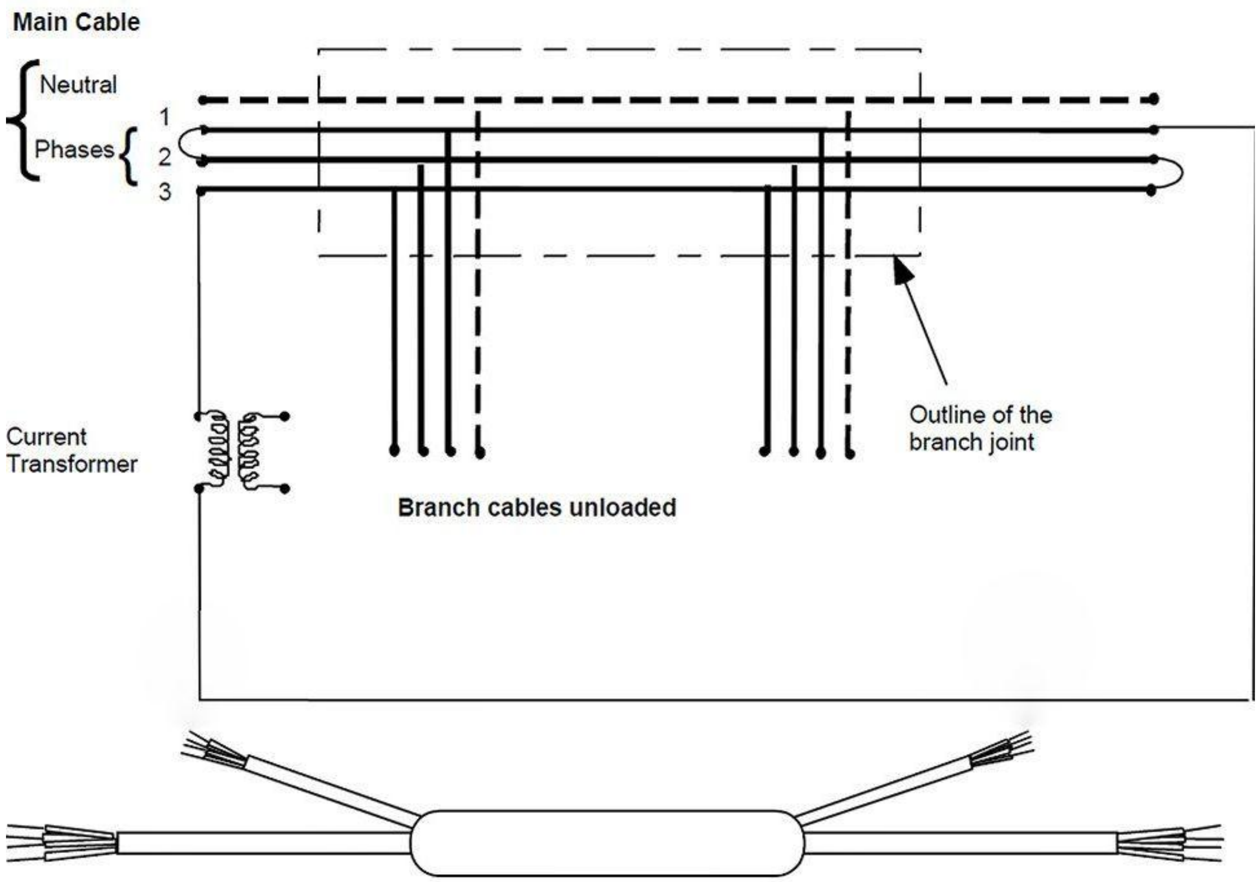


Fig. 3.5 - Test configuration for branch joint [5]

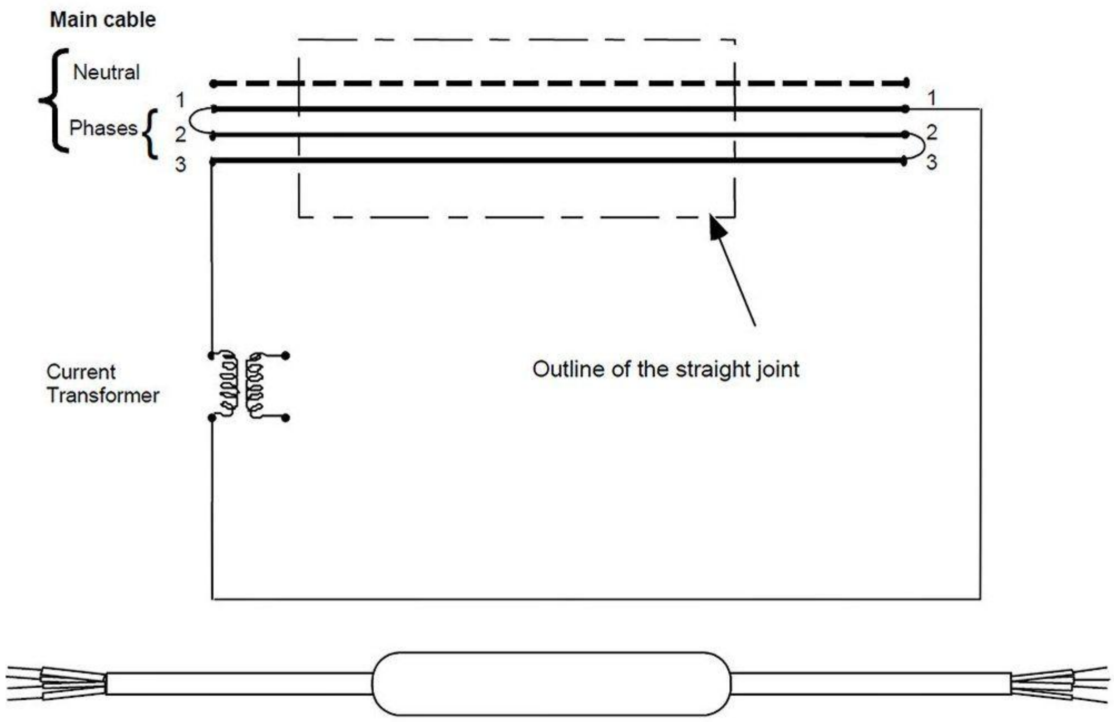


Fig. 3.6 - Test configuration for three phase cables on a straight joint [5]

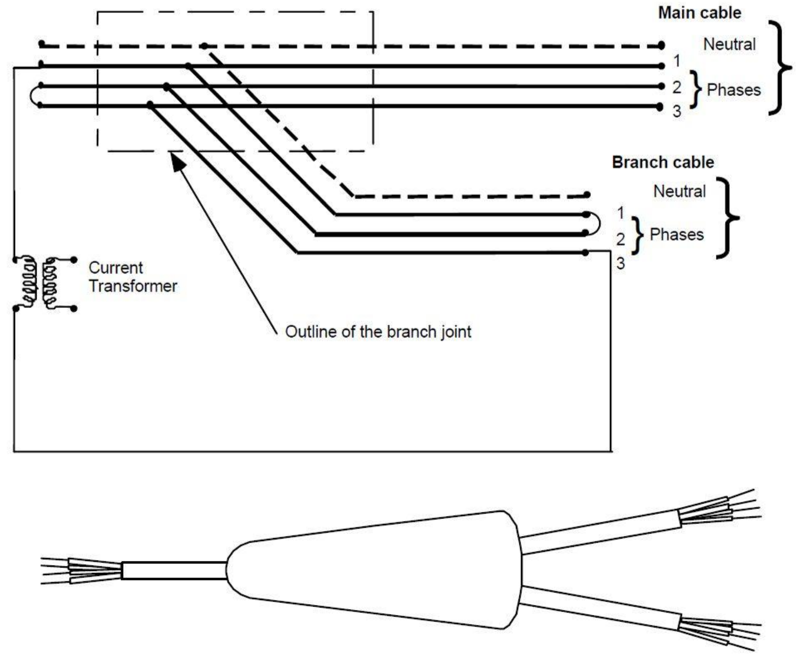


Fig. 3.7 - Test configuration for three-phase main and branch cables of equal conductor cross-section on a branch joint [5]

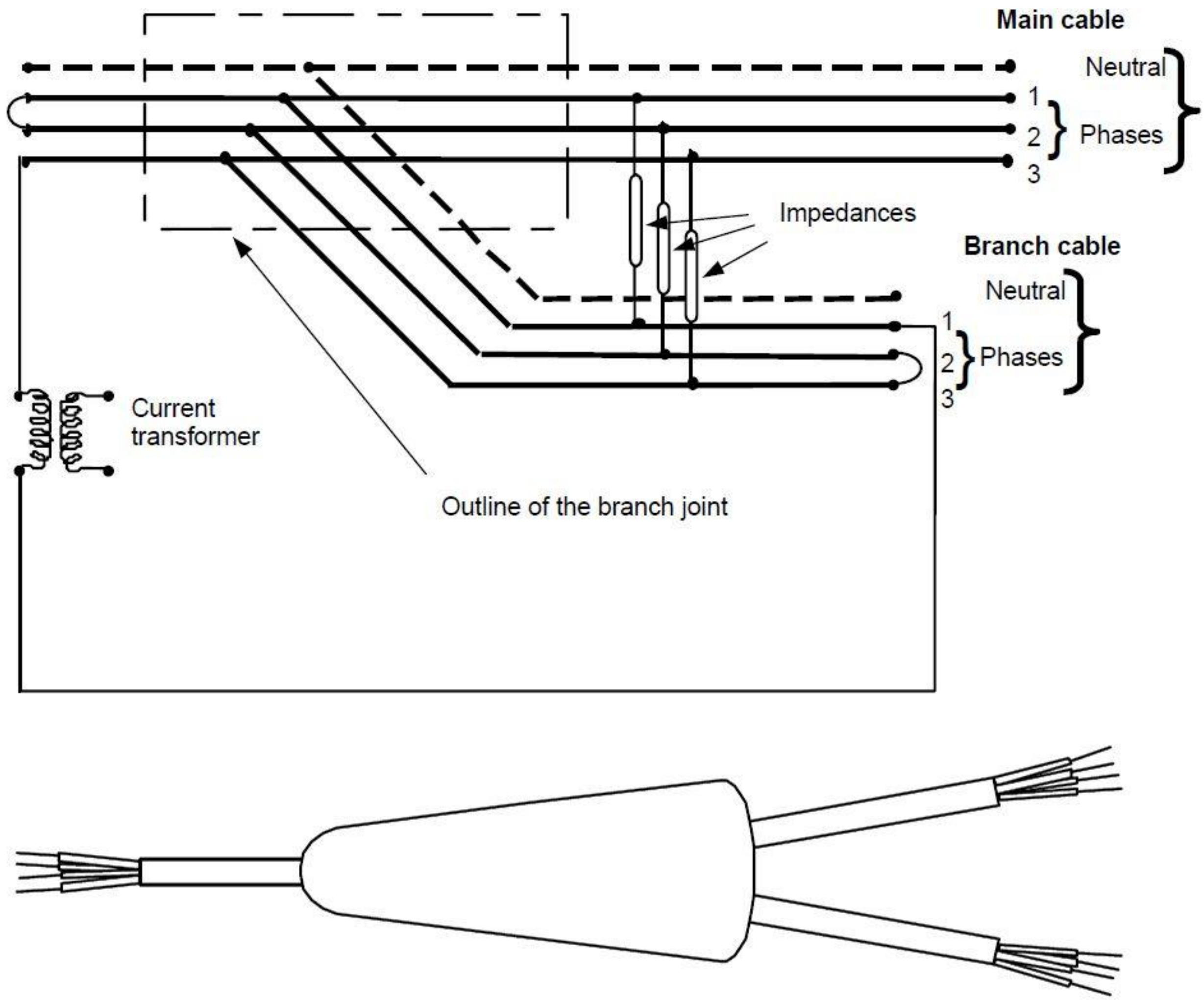
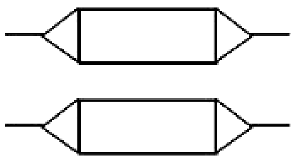
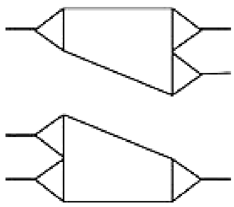
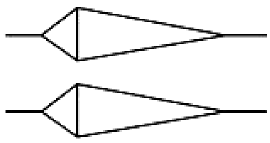
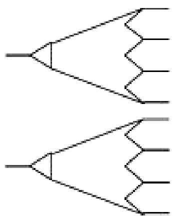


Fig. 3.8 - Test configuration for three-phase main and branch cables of unequal conductor cross-section on a branch joint [5]

3.3.4 Number of test samples and conductor cross-section [5]

The following table gives the number of conductors required for testing as well as the conductor cross-sections to be used for testing. Cables used for testing shall comply with HD 603 as well.

Test sequence	Accessory	No of samples	Type of accessory	Test	No of cycles
Test sequence for joints for solid extruded dielectric insulated cables and for transition joints between solid extruded dielectric insulated cables and impregnated paper insulated cables	Straight joint		Type I, Type II & Type III joint	Heating cycle test in air	63
				Heating cycle test in water	63
	Branch joint		Type I, Type II & Type III joint	Heating cycle test in air	63
				Heating cycle test in water	63
Test sequence for outdoor terminations on solid extruded dielectric insulated cables	Outdoor termination		Type I & Type II termination	Heating cycle test in air	63
				Heating cycle test with crutch immersed	63
			Type I & Type II termination	Heating cycle test in air	63
				Heating cycle test with crutch immersed	63

Type I joint: Joints for which impact withstand, impulse voltage withstand and metallic screen short-circuit current withstand tests are not required
Type II joint: Joint tested for impact withstand but not for impulse voltage withstand or metallic screen short-circuit current withstand
Type III joint: Joint tested for impulse voltage withstand and metallic screen short-circuit current withstand but not for impact withstand
Type I termination: Termination where impulse voltage withstand is not required
Type II termination: Termination tested for impulse voltage withstand

Table 3.2 - Test specification [5]

3.4 Range of compliance [5]

For obtaining compliance for the accessories for a range of cross-section, the largest and the smallest cross-sections of the cables are tested with the accessories. If the accessories pass the test for both the cross-sections compliance is obtained for those cross-sections as well as all the intermediate cross-sections. If only one cross-section is used for testing compliance for that cross-section only shall be given. If tests are done on one type of insulation compliance can be extended to other types of insulations as given in table 3.3. However if the cables have different sheathing materials then the compliance shall only be given to accessories for cables made from the same sheathing material.

Compliance obtained by testing on a non water-blocked type of cable shall be extended to a water-blocked cable provided they have same design. However the converse shall not apply. Generally the joints are designed for withstanding 1 meter of water; however in some special applications this might not be sufficient. In such cases, upon agreement between manufacturer and user, the accessories shall be tested using an increased water height of 10 m (100 kPa). Testing at one water height will achieve compliance for that pressure only. Testing at both 1 m and 10 m water heights will achieve compliance for those water heights and all intermediate pressures.

Test cable insulation	Range of compliance
XLPE	XLPE, EPR, HEPR, PVC
EPR or HEPR	EPR, HEPR, PVC
PVC	PVC

Table 3.3 - Material compliance

3.4.1 Compliance for joints

If a branch joint has successfully passed a test sequence, compliance can be extended to the straight joint, provided they similar constructions and the seals are of same quality.

3.4.2 Compliance for transition joints

If a transition joint successfully completes a test sequence mentioned in table 3.2 compliance can extended to extruded solid dielectric insulated cable, if the impregnated paper insulated cable side of the joint has identical design and relevant and satisfactory performance of the moisture seals of the extruded solid dielectric insulated cable have been proven by examination.

3.5 Test report and results [5]

Test report shall clearly mention the test arrangement and test procedure applied to carry out the test. There shall be data provided on the technical specification of the product under test. The test report shall be signed by the personnel who is responsible the test as well as the representative of the test facility. In the case of Ensto Finland Oy the representative is the laboratory manager.

Following details about the cable used for testing shall be provided in the test report.

A. Rated voltage
B. Material, shape and cross-section of conductors
C. Details of construction
D. Principal cable dimensions

If the cable fails beyond any part of the accessory, the test shall be declared void without discrediting the accessory. Tests may be repeated using a new accessory and start from the beginning. Alternatively the cable can be repaired and test can be resumed whence it failed.

4. Test specification calculation for heat cycling test according to IEC 61442

Tests were carried out to estimate the rating voltage transformer and heating transformer. Tests for the calculations were performed in Ensto Finland Oy's own laboratory in Porvoo under supervision.

4.1 Calculation of heating transformer rating

4.1.1 Test object

Prysmian AHXAMK-W 3x300+35 20kV/24 kV cable was used as the test cable. Since the insulation for this cable was XLPE the nominal operating temperature the cable is 90^{o}C. So in accordance with the standard it was required to raise the temperature of the cable between 95^{o}C to 100^{o}C. 2 meter long single core cable was used for testing and a similar cable was used as auxiliary cable. This particular cross-section cable was chosen because it was the biggest cross-section cable for which Ensto Finland Oy made accessories.

4.1.2 Test setup

A heating transformer with sufficient rating was used to supply the current required to raise the temperature of cable to the required value. The test arrangement is shown in the Fig. 4.1.

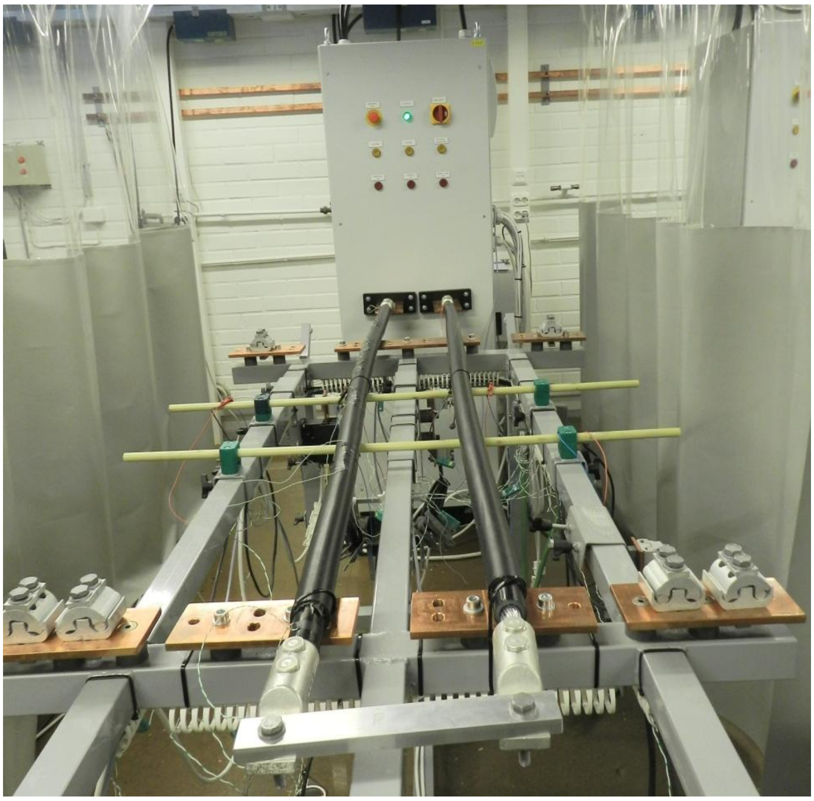


Fig. 4.1 - Test setup

4.1.2.1 Temperature measurement

K type thermocouples are used for temperature measurements. There were a total of 12 thermocouples used for measurement. 2 thermocouples were used for ambient temperature measurement and others were used to measure the conductor temperature as well as the surface temperature of the cable. Thermocouples were arranged 0,5 meter, 0,75 and 1 meter from either end of the cable to measure both surface and conductor temperature. Various measuring points were used to check if there is any significant variation in temperature depending upon the position of thermocouple. In order to measure the conductor temperature thermocouples were inserted into the cable so that it makes contact with conducting part and secured in position. Insertion was made with 2 mm drill bit. For measuring the surface temperature thermocouple was placed on the cable surface and two layer of aluminium tape was wrapped over it. On top of this several additional layers of PVC tape was also made.

Fig. 4.2 - Surface temperature measurement

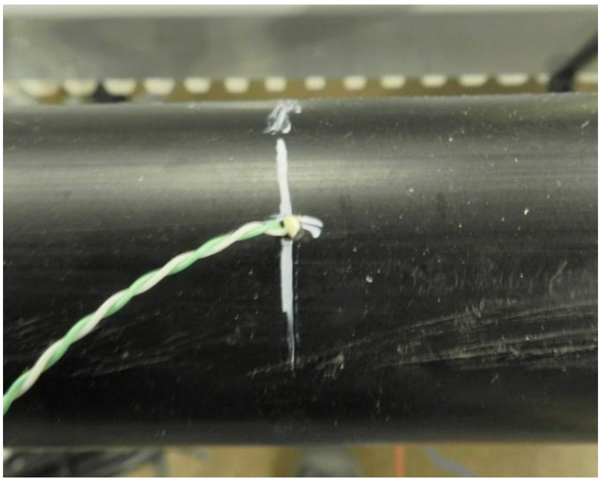


Fig. 4.3 - Conductor temperature measurement

Labview program was used for measuring and monitoring the current and temperature. Different current values were used to achieve the desired conductor temperature. Program recorded current and temperature values every 10 second interval. A screenshot of the test program is shown Fig. 4.4.

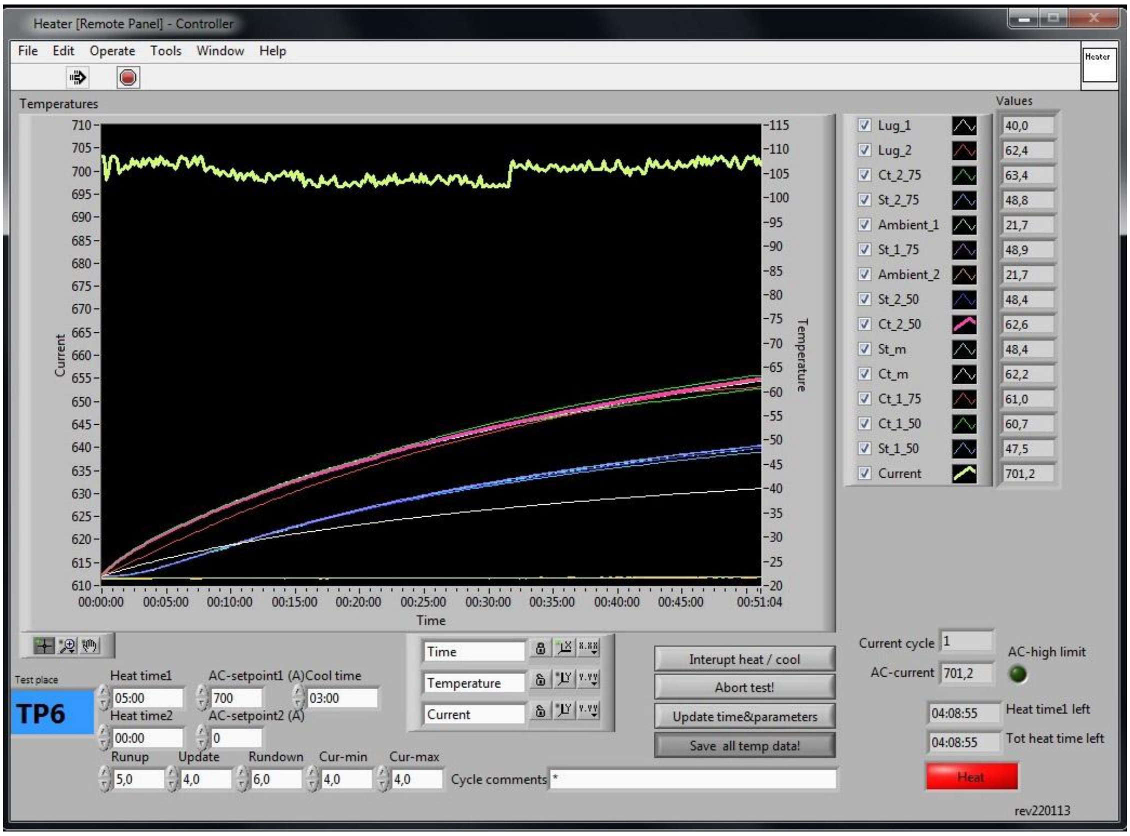


Fig. 4.4 - Labview program interface

4.1.3 Test result

According to IEC the duration of a single cycle should be at least 8 hours with a minimum natural cooling time of 3 hours. It is also essential to maintain not less than 2 hours of steady temperature during the test. It is considered that stabilization has been reached if the conductor temperature does not show any variation larger than 2 K within a 2 h period. For a current of 800A above mentioned conditions are met so the heating transformer should have a minimum rated current output of 800 A. The heat cycle for 800A current is given in the Fig. 4.5. Temperature and current versus time plot is given in Table 4.1.

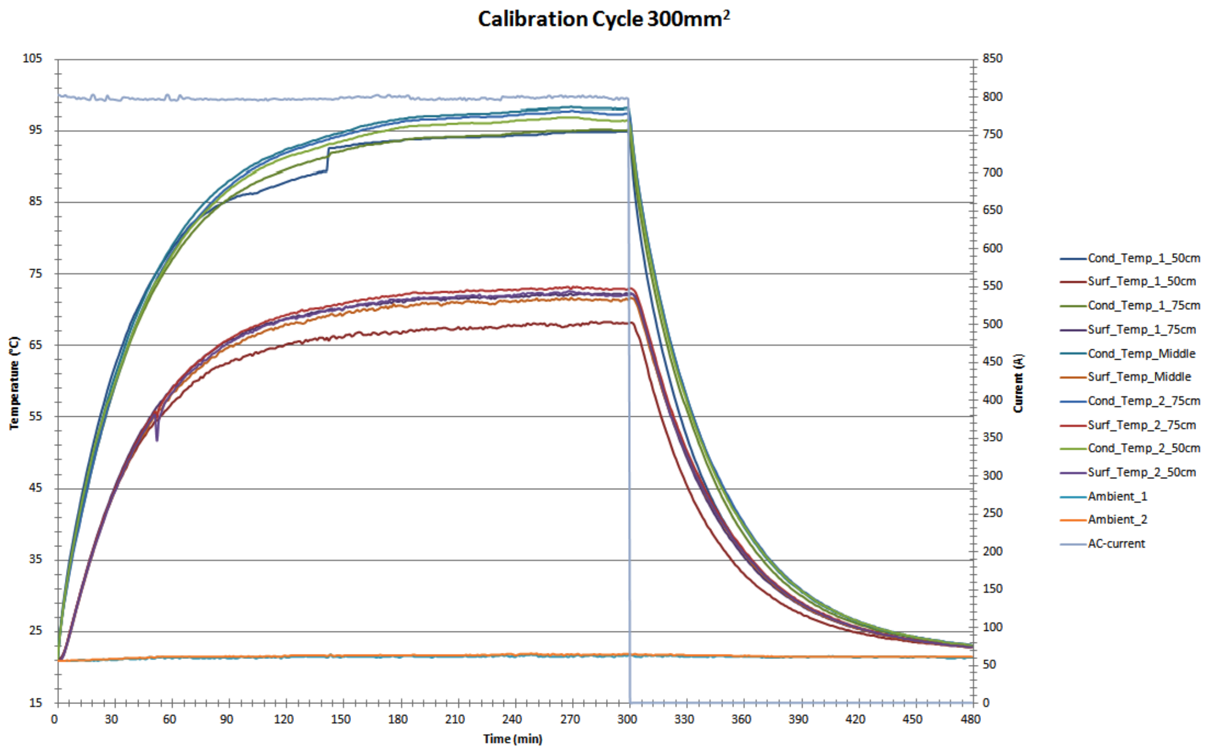


Fig. 4.5 – Heating cycle waveform at 800A current

Time [Min]	Conductor temperature at 50cm from end 1 [°C]	Surface temperature at 50 cm from end 1 [C]	Conductor temperature at 75cm from end 1 [C]	Surface temperature at 75 cm from end 1 [C]	Conductor temperature in the middle [C]	Surface temperature in the middle [C]	Conductor temperature at 75cm from end 2 [C]	Surface temperature at 75 cm from end 2 [C]	Conductor temperature at 50cm from end 2 [C]	Surface temperature at 50 cm from end 2 [C]	Ambient temperature 1 [C]	Ambient temperature 2 [C]	AC current [A]
0	21.4	21.2	21.2	21.1	21.2	21	21.1	21	21.1	21	21	20.9	803.1
30	62.2	44.7	59.5	45.3	60.8	44.8	59.6	44.9	59.8	44.6	21.1	21.2	797
60	78.7	57	77.2	59.2	79.1	58.4	78.1	59	77.8	58.4	21.3	21.5	796.5
90	85.5	62.6	85.8	65.9	88.2	64.9	87.4	65.9	86.9	65.4	21.3	21.6	797.4
120	88	65.2	89.7	68.9	92.6	68	92	69.3	91.3	68.7	21.4	21.6	797
150	92.8	66.2	92.3	70.2	95	69.4	94.4	70.9	93.6	70.2	21.5	21.7	799.3
180	93.6	66.7	93.7	71.4	96.8	70.6	96.3	72	95.4	71.3	21.5	21.7	800.7
210	94.1	67.6	94.2	71.6	97.4	71	96.8	72.5	96	71.9	21.5	21.7	798.4
240	94.4	67.8	94.7	71.9	97.8	71.3	97.2	72.8	96.4	72	21.5	21.7	799.8
270	94.8	67.8	95.1	72.1	98.3	71.5	97.8	73.2	96.8	72.5	21.5	21.8	801.2
300	93.2	68.2	94	72.4	96.8	71.7	96.4	73	95.4	72.1	21.7	21.9	0
330	52	45.2	55.8	49.1	57.5	49.6	57.5	50.1	56.9	49.5	21.5	21.7	0
360	36	32.9	38.4	35.3	39.5	35.8	40	36.2	39.7	35.9	21.5	21.7	0
390	28.8	27.4	30	28.6	30.5	28.8	30.8	29.1	30.7	28.9	21.5	21.5	0
420	25.4	24.8	26	25.4	26.3	25.4	26.5	25.6	26.4	25.6	21.4	21.5	0
450	23.8	23.5	24	23.8	24.2	23.7	24.3	23.8	24.2	23.8	21.5	21.5	0
480	23	22.9	23.1	22.9	23.1	22.9	23.1	22.9	23.1	22.9	21.4	21.5	0

Table 4.1 - Temperature, current versus time

Conductor and surface temperatures at various lengths were more or less the same, except for conductor and surface temperature near the end 1 (transformer side). The lower value of conductor temperature may be due to the large copper connecting plate used for connecting the cable to transformer. The surface temperature might be affected due to the presence of air ventilation outlet present directly on top of it. So the test area shall be such that there shall be no artificial air flow and all the connecting accessories used shall be of similar dimension to that of the accessories under test.

It is also advisable to plot a graph between the conductor and surface temperature during the calibration cycle so that there shall be some reference showing relationship between conductor and surface temperature since during the actual test only the surface temperature would be measured and conductor temperature would be calculated by means of calculation mentioned in 2.4.2. Fig. 4.6 shows sample graph of conductor temperature V/S Surface temperature. It can be seen that graph is almost linear.

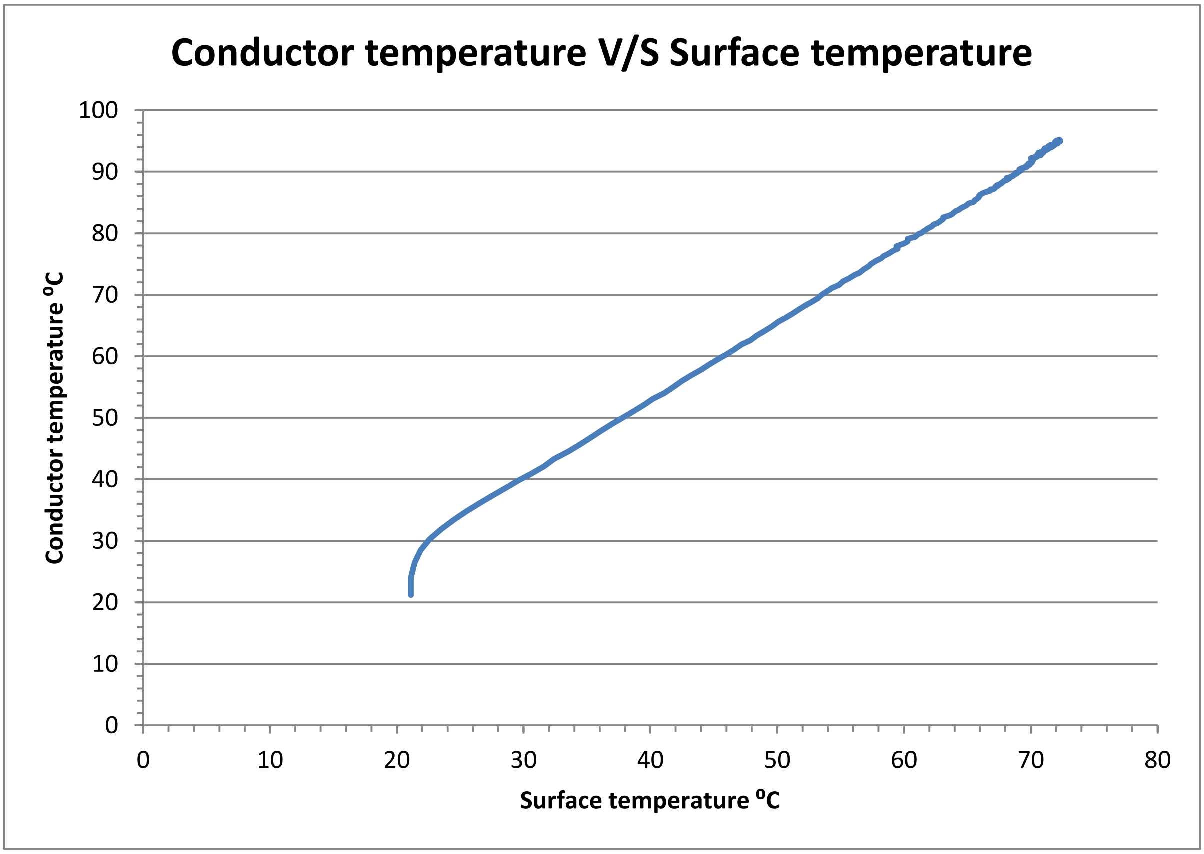


Fig. 4.6 - Conductor temperature V/S Surface temperature

4.2 Calculation of high voltage transformer rating

Required current value for the testing transformer is found out by three different methods. It is assumed that the current flowing in the test cable is mainly capacitive so other components of current can be neglected. Since part of the semiconductor layer is removed at terminations capacitance due to them can neglected.

A. By applying the maximum test voltage to the largest size conductor for which the accessories are made, and directly taking the current reading from milliamp meter
B. By calculating the current directly from the capacitance value obtained from catalogue.
C. By measuring the capacitance of a sample cable length and using that to find the current.

The capacitive current required deepens upon the length of the cable. The cable length is decided so that it is possible to test simultaneously 2 three phase accessories with following configuration.

1 m + 2 m +2 m + 2 m + 1 m (termination + cable + joint + cable + termination)

Here the 2 meter length of cable is the minimum length required by the standard. Lengths of joints and termination are the maximum length obtained from Ensto Finland Oy's product catalogue.

Deducting the one meter terminations at the end (since semiconductor layer is completely removed for termination) the effective length of cable with capacitance is 36m and adding an auxiliary cable of length 10m with a possibility to take 2 turns around the heating transformer total length is 46m

4.2.1 Method A

4.2.1.1 Test object

Prysmian AHXAMK-W 3x300+35 20kV/24 kV cable was used as the test cable. 300 mm^2 was chosen because it has the highest capacitance for which the accessories are made for. The effective cable length used for testing was 3,35 since about 0,5 meters of semiconductor layer was removed from either side of the cable to prevent flashover from connecting lugs to the semiconductor layer.

4.2.1.2 Test setup

A high voltage transformer with sufficient rating was used to supply the test voltage of 52kV. This voltage corresponds to a nominal voltage of 20 kV which is the maximum nominal voltage for tested accessories. The test arrangement is shown in the Fig. 4.7. Controlling and monitoring apparatus is given Fig. 4.8.

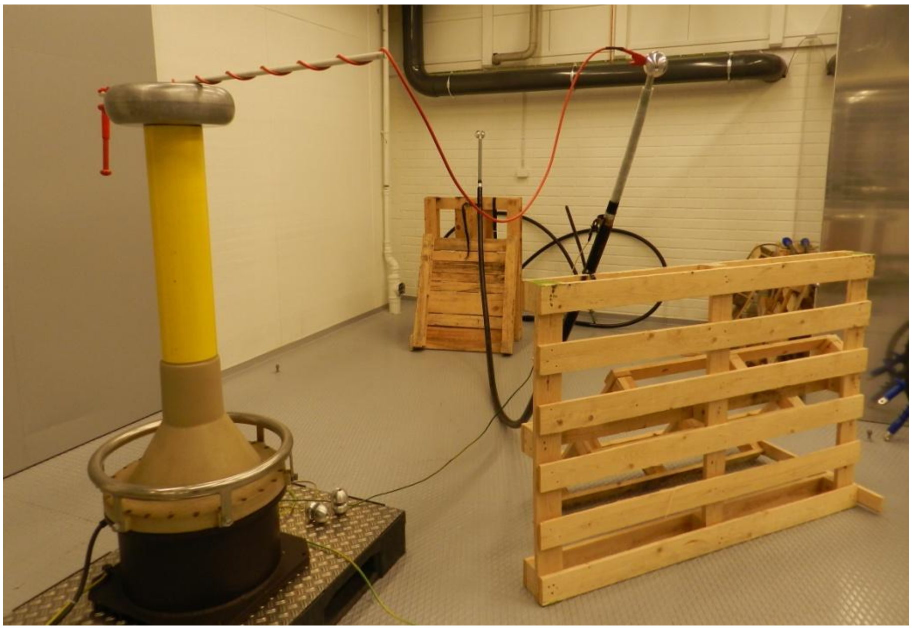


Fig. 4.7 - High voltage test setup

Fig. 4.8 - Controlling and monitoring apparatus

The current requirement for applying 52 kV to the 3,35 meter cable was found out from the ampere meter = 26 mA

So current per meter of the cable is I_A /m = 26/3,35 = 7,761 mA

So the total current requirement for maximum configuration is = 7,761x46 = 357 mA

4.2.2 Method B

Cable capacitance obtained from the cable catalogue = 0,32 μF/km

Total cable capacitance for 46 meter of cable = $14,72 \times 10^{-9}$ F

The capacitive current in milliamps can be calculated by means of the following equation.

$$I_C = 2\pi f V C * 10^3 \text{ ------------------------------ (4.1)}$$

Where f is the frequency of AC voltage, C is the total capacitance and V the test voltage (52kV).

Substituting all the values current required is I_B = 240,3 mA

4.2.3 Method C

The capacitance of 2,35 meter of cable is measured using multimeter the capacitance was found to be = 1nF

So capacitance per meter = $0,43 \times 10^{-9}$ F

Substituting in equation 4.1

Required current I_C = 323 mA

4.2.4 Result

By comparing the values of method A, B and C highest current value is chosen.

So the required minimum current value is = 357 mA

And required minimum voltage value is = 52 kV

4.3 Selection of test equipment

Based on the requirements and taking into account necessary margin 700 Series AC Dielectric Test Set rated at 40 kVA was chosen as high voltage test transformer and Load cycle DS04 with single CT cart rated at 12.5V was chosen as high current test transformer. Technical specifications are given appendix B.

5. Impulse voltage test according to IEC 61442

The purpose of the impulse voltage test is to make sure that the cable accessories withstand lightning overvoltages which may occur in service. The impulse generator design is based on the Marx circuit and replicates standard lightning impulse voltage waveform.

5.1 Shape of test voltage and test specifications

Figure of standard lightning impulse wave with associated time parameter is given below

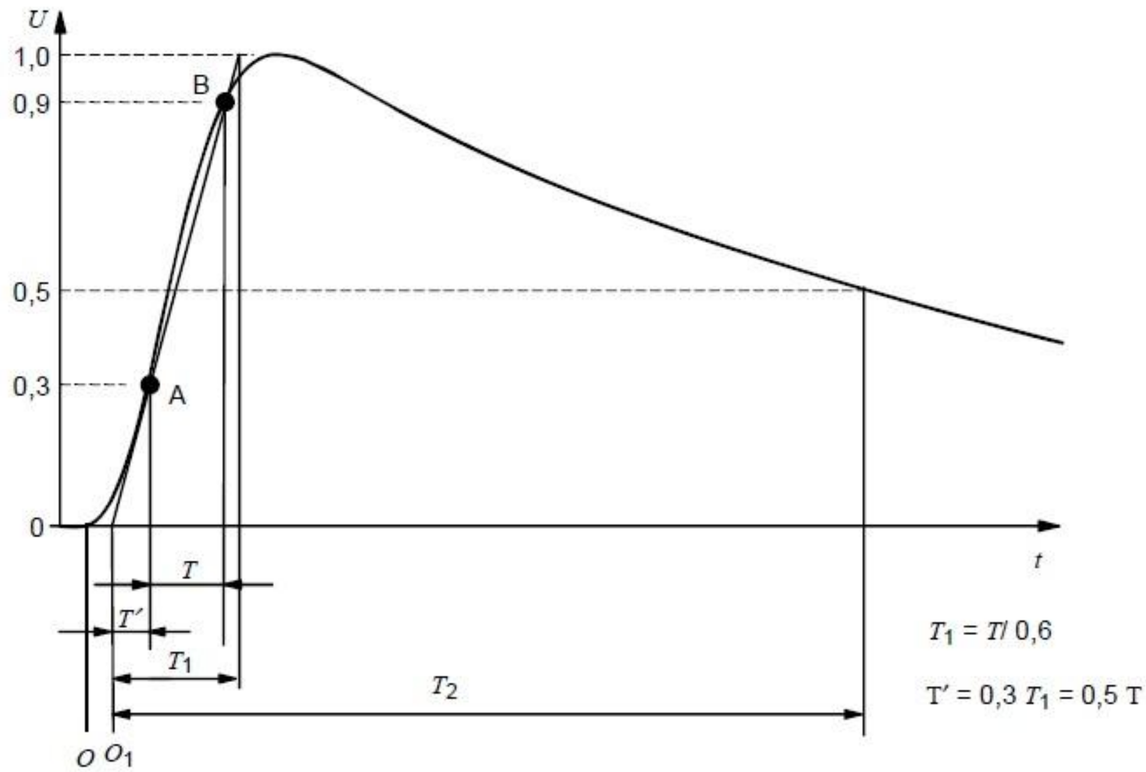


Fig. 5.1 - Standard lightning impulse voltage waveform [3]

Virtual origin O_1 instant preceding that corresponding to point A, of the test voltage curve by a time 0,3 T_1. Front time T_1 is defined as 1/0,6 times the interval T between the instants when the impulse is 30 % and 90 % of the peak value on the test voltage curve. Time to half-value T_2 is defined as the time interval between the virtual origin, O_1, and the instant when the test voltage curve has decreased to half the test voltage value.

As per IEC 60230 the impulse waves applied shall have a wave front of duration between 1 µs and 5 µs, and duration to half the peak value of 50 ± 10 µs. In addition to this standard IEC 60060-1 imposes constrains on test voltage to be within ±3% and relative overshoot to magnitude to not exceed 10%.

The peak voltage requirement as per HD 629 is given in the following table.

Rated voltage $U_0/U (U_m)$ kV									
3,6/6(7,2)	3,8/6,6(7,2)	6/10(12)	6,35/11(12)	8,7/15(17,5)	12/20(24)	12,7/22(24)	18/30(36)	19/33(36)	20,8/36(42)
60	60	75	95	95	125	125	170	194	200

Table 5.1 - Test voltage for impulse test [2]

While conducting the test for three-core accessories, one phase shall be tested at a time, with the other two phases earthed. Impulse test according to IEC 61442 is done at ambient temperature as well as at elevated temperature. Temperature of the cable for test at elevated temperature depends on insulation of the cable used for testing. . This temperature is 5 K to 10 K above the maximum cable conductor temperature in normal operation for extruded insulation cables and 0 K to 5 K above the maximum cable conductor temperature in normal operation for paper insulated cables. This temperature should be maintained before as well as after the test.

Impulse testing at elevated temperature follows all the general conditions of IEC 61442 mentioned earlier in 2.1 where ever applicable. Since the direct measurement of temperature is not possible due to the presence of impulse voltage the conductor temperature is measured as per clause 8 of IEC 61442 which is already explained in section 2.4. Test procedure is based on IEC 60230, which will be discussed later.

5.2 Marx circuit

A Marx circuit is one of the most commonly used setup to create impulse voltage waveform. It achieves this purpose by charging a number of capacitors in parallel and once they are fully charged, discharging them in series. This parallel charging of capacitors helps to build up the test voltage to desired level [10]. Basic circuit diagram of a 3 stage Marx circuit is given Fig 5.2.

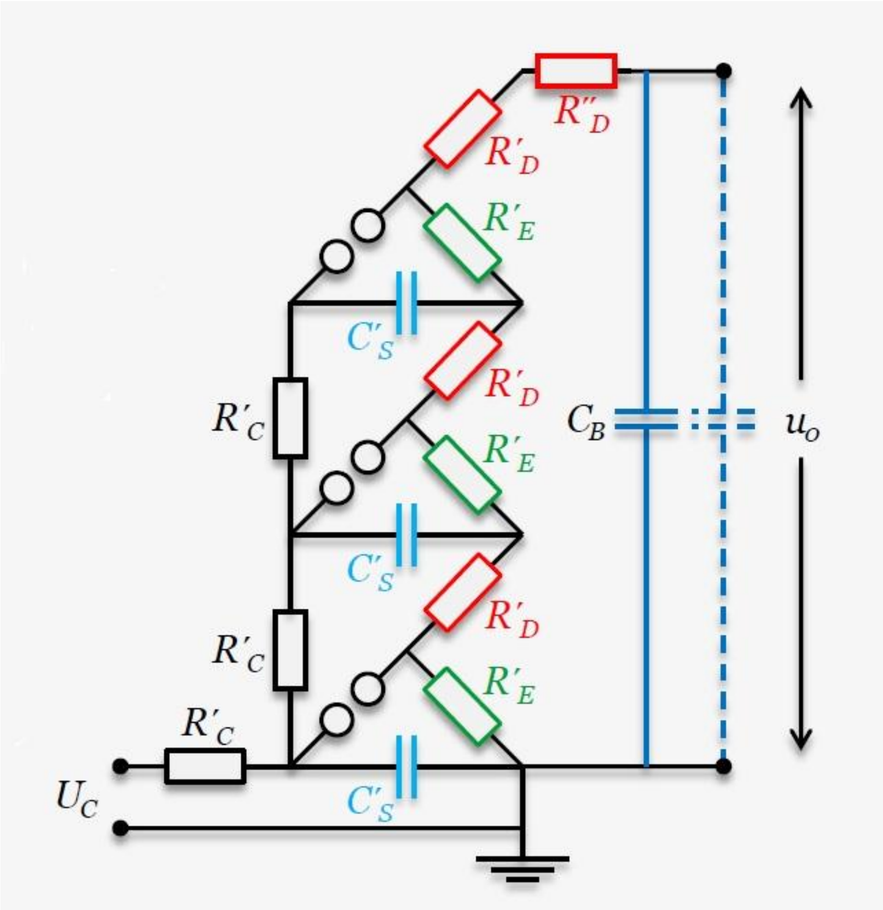


Fig. 5.2 - Marx generator circuit diagram [16]

Initially a high voltage DC supply charges the capacitors C'_s in parallel through the charging resistors R'_c as well as through the discharge resistances R_2 (parallel combination of R'_E, $R_2 \approx 3R'_E$). The charging resistor has high resistance value to limit the current to protect source [16]. Spark gaps are used to control the charging and discharging of the capacitors. The breakdown value of the spark gap is higher than that of the charging voltage so they will be open circuited during the charging time. Also the breakdown value increases slightly up the stage, which is essential for the consistent operation of the circuit [11]. It is also necessary that the axes of the gaps should be in the same vertical plane so that the ultraviolet radiations due to spark in the first gap, will irradiate the other gaps [11]. This provides enough supply of electrons initiate breakdown during the short period when the gaps are subjected to voltages from the charging capacitors.

Once all the capacitors are charged to desired value the first gap would be triggered, which would cause the gap to breakdown and the is thus short circuited. This causes the first two capacitors to come in series, resulting in a voltage of about 2V across the second spark gap. All other gaps would be short circuited as well until all the capacitors are series connected. Ideally, the output voltage will be 3V; the number of capacitors times the charging voltage, but in practice the value is less. When the capacitors are discharged, the spark gaps stop conducting and the high voltage supply begins charging the capacitors again.

Damping resistance, which is the series combination of the R'_D resistances and R''_D, and load capacitance, which is the parallel combination of C_B and the test object capacitance determine front time and time to peak [16]. Discharge resistance, which is the series combination of R'_E and surge capacitance, which is the parallel combination of the C'_s determine time to half value [16].

5.3 General construction of impulse voltage test system

Apart from the impulse voltage generator a typical impulse voltage test system consists of a charging unit, a voltage divider and a control and measurement system. Fig. 5.4 is an example of a 4-stage impulse voltage generator (IVG) with a capacitive voltage divider (CVD) and a charging unit (CU). The charging unit usually consists of a step up transformer and rectifier. The capacitive voltage divider is used for measuring the impulse voltage. Cathode ray oscillographs are usually used for measurement and recording of the lightning impulse waveform.

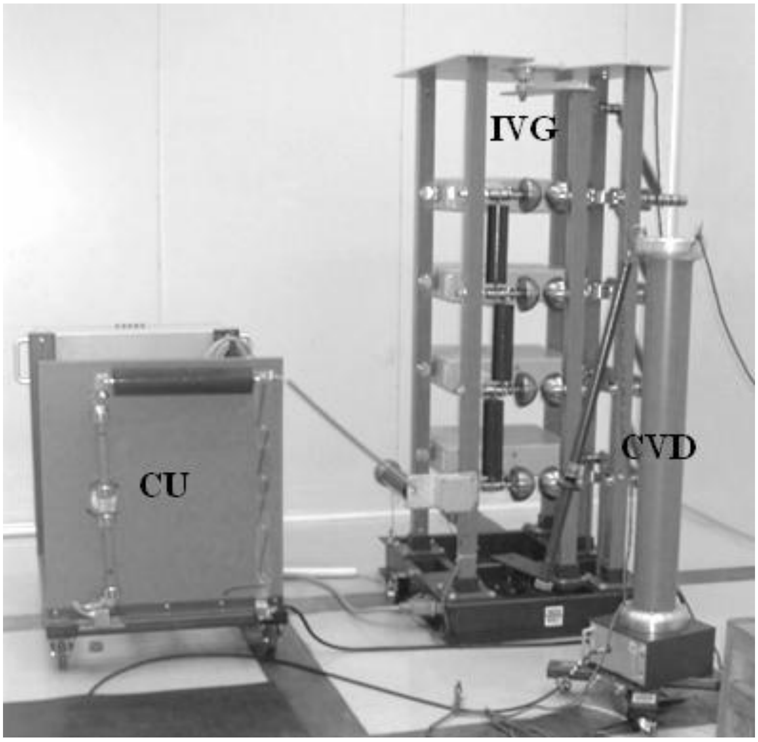


Fig. 5.3 - Example of a 4 Stage impulse voltage generator system [12]

5.4 Preparation of test cable [13]

As per IEC 60230 the test cable shall be subjected to the bending operation mentioned in relevant IEC standard however since IEC 61442 does not mention any bending operation it is not necessary. If client requires such mechanical operation to be performed it can be agreed between the client and the testing facility to carry out such operation.

When impulse test is carried on terminations, there should be at least 5 m of free cable after the termination. For impulse test on joints there shall be a minimum 5 m length of free cable between the joint and the bottom part of both the sealing end. If there are more than one joint in a test installation there shall be at least 3 m length of free cable between the successive joints.

5.5 Calibration of impulse generator

Impulse generator should always be calibrated before use. For tests at elevated temperatures calibration can be performed immediately before or during the period when the temperature of the cable is maintained at a constant value. For the calibration both ends of the test assembly shall be connected to the impulse generator. For calibration purpose a measuring sphere-gap, oscillograph and a voltage divider can be used. All of these shall be connected parallel to the impulse voltage generator and remain connected till the test is finished [13].

In order to calibrate the impulse voltage generator three different settings of the measuring sphere-gap are used. The gap lengths are adjusted for each of these settings so that flashover occurs at 50 %, 65 % and 80 % of the desired test level [13]. The voltage of the generator is adjusted so that 50% flashover of the gap occurs for each setting of the sphere-gap. An oscillogram of the impulse voltage shall be taken for reference.

A curve of the sphere-gap flashover voltage shall be drawn against the charging voltage. Using this curve it is possible to predict the charging voltage for specific flashover voltages by extrapolating it. It shall be noted that the voltage divider used for measurement purpose shall have the same setting throughout the test and also it shall adequate range to cover the maximum flashover voltages that need to be measured.

5.6 Procedure for impulse voltage test [13]

A series of ten impulses are applied to the test object at the level specified in table 5.1. After each pulse the impulse generator is charged to the desired level and triggered to discharge the stored energy onto the test object. The impulse generator shall be calibrated again for the negative polarity in order to continue testing. Same voltage level from table 5.1 is used for testing the negative polarity as well. Oscillograms of the pulses are recorded for future reference. These oscillograms shall include timing oscillation, voltage waveforms, ambient temperature, cable temperature etc. Sample oscillogram for negative pulse and positive pulse is given in Fig. 5.4 and Fig. 5.5 respectively. It shall also be noted that the cable shall be maintained at the required temperature as given in IEC 61442.

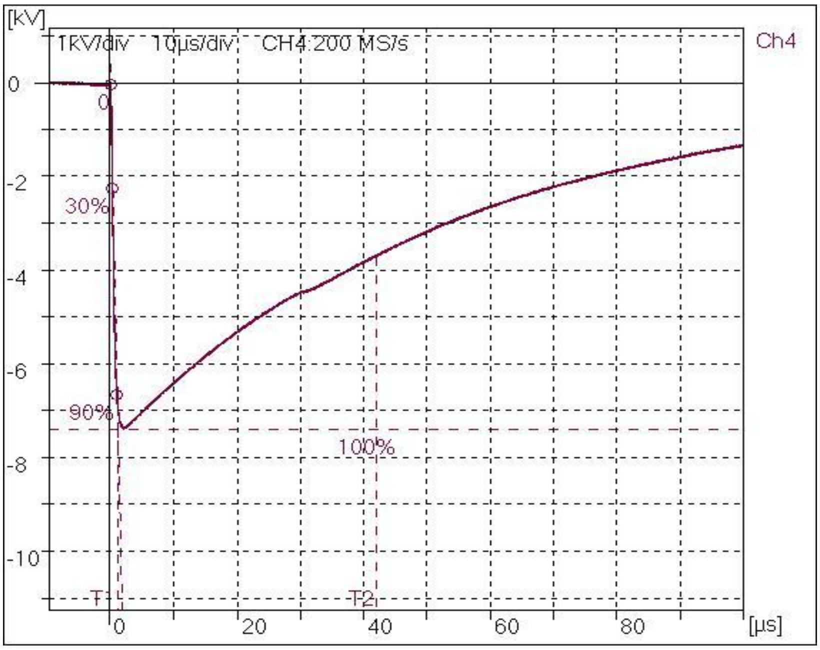


Fig. 5.4 - Sample oscillogram for negative polarity

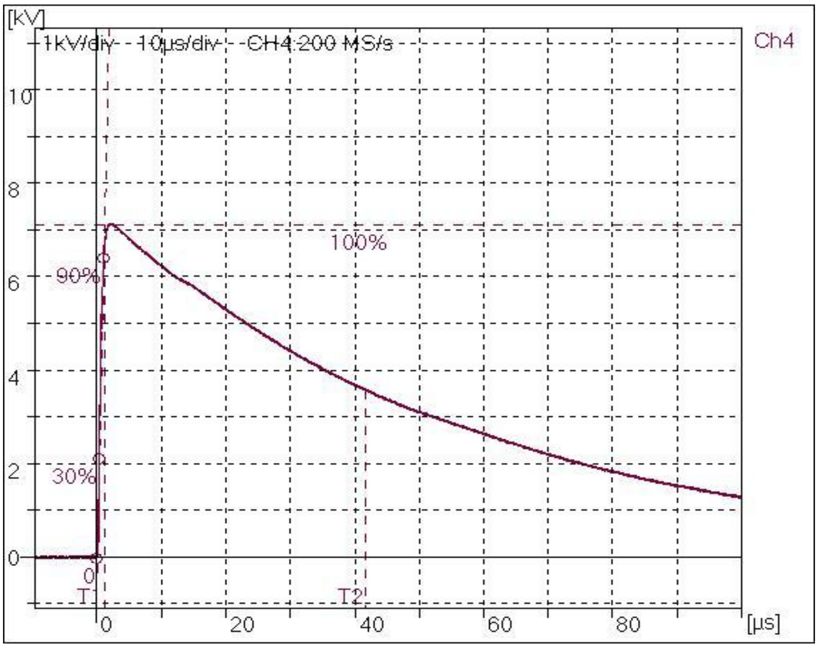


Fig. 5.5 - Sample oscillogram for positive polarity

5.7 Impulse voltage test above the withstand level [13]

The main purpose impulse voltage testing at Ensto Finland Oy is to test the prototypes for compatibility with standard and also to evaluate their performance, so most of the time theses prototypes are tested well above the limits specified by the standard. IEC 60230 provides the procedure to safely test at the products at higher level of voltages, which is discussed below.

Reference: [13]

1) *10 negative impulses at withstand voltage + 5 % of withstand voltage*
2) *5 positive impulses, the first at 50 % of the value used for 1 and the remainder at progressively increasing values up to 85 % of the value used for 1*
3) *10 positive impulses at withstand voltage + 5 % of withstand voltage*
4) *10 positive impulses at withstand voltage + 10 % of withstand voltage*
5) *5 negative impulses, the first at 50 % of the value used for 4 and the remainder at progressively increasing values up to 85 % of the value used for 4*
6) *10 negative impulses at withstand voltage + 10 % of withstand voltage*

The above sequence shall be repeated with approximately 5% increments of voltage till the desired voltage level is attained or till breakdown of the test object occurs.

5.8 Selection of test equipment

According to IEC 61442 the maximum impulse voltage test voltage is 200 kV. Adding necessary margin and the possibility to test beyond 200 kV for research purposes, the final rating was decided to be 400 kV. HIVG 400kV-20kJ Impulse voltage generator from Himalayal Corporation Limited was chosen based on the cost and concurrence with Ensto Finland Oy’s requirement. Technical specifications are given in appendix A.

6. Impulse test according to EN50393

This test is used as a pre-test before running the full test sequence, that the accessory meets the network impulse requirements. The accessory shall be installed on a test loop in accordance with the manufacturer's installation instructions.

6.1 Test configuration

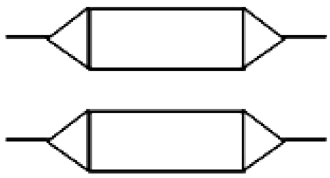
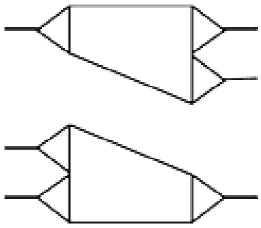
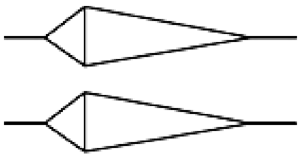
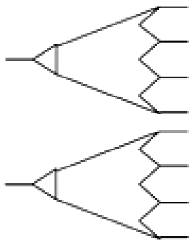
Test sequence	Accessory	No of samples	Type of accessory
Test sequence for joints for solid extruded dielectric insulated cables and for transition joints between solid extruded dielectric insulated cables and impregnated paper insulated cables	Straight joint		Type III joint
	Branch joint		Type III joint
Test sequence for outdoor terminations on solid extruded dielectric insulated cables	Outdoor termination		Type II termination
			Type II termination
Type III joint: Joint tested for impulse voltage withstand and metallic screen short-circuit current withstand but not for impact withstand Type II termination: Termination tested for impulse voltage withstand			

Table 6.1 - Test configuration [5]

6.1 Test procedure

6.1.1 Calibration of impulse voltage waveshape

Using an approved measuring system, the waveshape of the impulse voltage applied to the test object shall be verified using impulses not less than 50 % of the test voltage level. Method mentioned in section 5.5 can be used.

6.1.2 Procedure for impulse voltage test [5]

The test shall be conducted at ambient temperature. Impulses shall be applied to each phase in turn with the other phases, neutral and screen earthed.

A series of 10 positive and 10 negative impulses shall be applied at the values below:

- 8 kV for accessories installed on a main cable with a conductor cross section ≤ 50 mm².
- 20 kV for accessories installed on a main cable with a conductor cross section > 50 mm².

In the case of a branch joint, the conductor cross-section of the branch cable is not relevant. The requirements of the test are satisfied if no indication of disruptive discharge or partial breakdown is obtained. The relevant technical committee shall specify the criteria for identification and evaluation of partial breakdown, where applicable [14].

7. Electrical safety

Taking in to account the level of voltage and current involved in the tests it is essential to take necessary steps to prevent any kind of accidents. The standard for erection and operation of electrical test equipment is EN 50191, the Finnish translation for this standard is SFS-EN 50191. It provides instructions about the safety clearances and the step to be followed to safely conduct electrical testing. This standard applies to test stations, test laboratories and temporary test stations either running manned or unmanned, with or without automatic protection. I would be discussing mostly about the test stations without personnel in permanent attendance, since this would be the case for most long duration tests.

7.1 Erection of test installations

7.1.1 General safety requirements [7]

As per the standard the test assembly shall be setup in such a way that direct contact is prevented by insulation of live parts, covers, enclosures wherever possible, however in the heat cycling test and impulse test is unavoidable to prevent direct contact with above motioned means, so direct contact can be prevented with the help of using barriers or obstacles. The barriers shall be so designed as to: prevent access to the test area by persons other than the test persons; prevent persons other than the test persons reaching the prohibition zone (prohibition zone is the volume around live parts which should not be breached if full protection against direct contact with these parts is not provided); prevent persons outside the barrier reaching the operating devices of test installations which are located inside the barrier. Generally the barriers used for preventing direct contact are fences made of conducting material in which they shall be earthed. Clearances required for safe operation of equipment is discussed in section 7.3 of this document.

The following are some of the minimum requirement to ensure safety in a testing facility

1. Test area and test installations shall be clearly marked with warning signs to prevent unauthorized personnel from entering test area.
2. There shall be indicator lights displaying the operational status of the test equipment. Red color indicating the test circuit is active and green indicating test circuit is inactive.
3. The test installations controls and test circuits shall be clearly marked.
4. Entrances shall be provided with a warning sign “No unauthorized persons beyond this point”
5. When the high voltage test is carried out there is possibility that voltages would be induced in nearby metal structures, so the test assembly shall be so designed in such a way that this does not happen.

6. If an isolating transformer is used for supplying any equipment in the test circuit which is energized, then the isolating transformer shall have at least the same rating as that of the equipment that it is supplying.
7. An emergency switch-off facility shall be provided both inside and outside the test area to cut-off the electricity in case a situation arises that could compromise the safety of personnel or cause damage to testing equipments.
8. There should be means provided to prevent unauthorized turning on of the test circuit.
9. There shall also be interlocks provided to prevent automatic energization of the test circuit when the mains voltage is resumed after a power failure. However this may be omitted, provided that this will not cause any hazards.
10. There should provision to discharge the residual voltage in the testing area. This can be achieved by using grounding rod to earth the test piece after the test.

7.1.2 Safety requirements for the installation

Since heat cycling tests are long duration tests, they are running major part of the time without supervision. For example test duration for heating cycle voltage test in air for outdoor terminations could last minimum of 42 days so it is not possible to supervise the test for the whole duration so test area shall be designed taking this fact into account.

The barriers used shall be solid walls or grids at least 1 800 mm high [7]. These barriers shall have wheels for moving around the test area and they shall also have lifting hooks. In our particular case there would be multiple test areas in the same room so the operational status of individual test areas shall be indicated by means of separate signal lights [7]. The layout of the test station and positioning of the barriers shall be done so that it would be possible to access each test areas separately irrespective of if other test area is operational or not. This is essential in our case because we would be running impulse voltage test, which is a short duration test and heating cycle test which is a long duration test. So we would have to access each test areas independent of each other. A possible layout of the test area is discussed in section 7.3.

Emergency escape doors, gates, etc. shall be able to be opened from the inside of the test area [7]. Doors, gates, barriers etc that are placed to prevent unauthorized entry shall not prevent persons from leaving [7]. Areas including those outside the test area where capacitive charging is likely to take place, shall be separated by additional barriers for the duration of the testing [7]. This case is not taken into account for making the layout, since the sketch of the actual room where the test is going to be carried out is not available.

7.2 Operation of test installations

7.2.1 General requirement for operation of the test station [7]

1. Operation of the test deices shall only be carried out under the supervision of skilled person.
2. Operating manual of the test devices shall be provided to the person conducting the test. This should contain adequate information on how to conduct the test safely.
3. The test installations used shall be inspected prior to the operation.
4. Maintenance of the test installations shall be carried out by only skilled persons.
5. All the safety devices shall be inspected by a skilled person at suitable intervals of time and record all these inspections shall be maintained.
6. Only skilled or instructed persons may work with test installations.
7. All personnel involved shall be instructed in the safety requirements, safety rules and company instructions applicable for their work.
8. A written record of the training provided to the personnel shall be maintained. At Ensto Finland Oy a similar system already exist, so this shall be integrated with it.
9. Test areas shall only be entered by the personnel employed there and other persons who have received adequate instruction regarding the hazards.
10. If other persons have to enter these areas, they shall be accompanied by a skilled person and their attention shall be drawn to the risks.

7.2.2 Preparation of tests and test procedure [7]

1. Only the nominated person in control of the work activity can perform switching operations. However he/she could delegate this task to another person.
2. Only the test persons are allowed in the test area once the test installations is made ready and it is the duty of the nominated person in control of the work activity to ensure this is strictly followed.
3. The safety of the operator shall be guaranteed in the following scenarios: electrical hazards, noise, explosions, radiations, flying parts, gas formation, fire or hazardous materials etc.
4. Generally assembly work and tests shall never be performed simultaneously however in exceptional cases skilled persons may enter the test area while the test is in progress provided they do not enter the prohibition zone.
5. If a fault happens during the test, it is possible that some part of the test object and test installations which are not live during normal operation can be subjected to dangerous voltages. If work has to be carried out on these parts, suitable insulating devices and auxiliary means shall be used.
6. After the test is done the test objects shall be earthed to avoid danger due to residual voltages due to induction.
7. Emergency routes and exits shall always be kept clear.

7.3 Safety clearances

Since the test involves high voltage there shall be necessary precautions taken to assure the safety of operating personnel. The following tables give necessary clearances for safe operation of the test equipment.

Width of opening (diameter or width) mm	Minimum distance from the prohibition zone mm		
	Slot	Square	Circle
over 4 to 6	10	5	5
over 6 to 8	20	15	5
over 8 to 10	80	25	20
over 10 to 12	100	80	80
over 12 to 20	120	120	120
over 20 to 30	850	120	120
over 30 to 40	850	200	120
over 40 to 120	850	850	850

Table 7.1- Minimum distance between openings in the barrier and the prohibition zone in relation to the width of the opening [9]

The above table gives the minimum distance the barrier shall be placed away from the prohibition zone. This is to prevent accidental electrical shock of personnel through the opening in the barrier. According to BS-EN 50191 the barrier height shall be at least 1800 mm for test laboratories. Barrier with 1800 height with square slot of side size 40 mm shall be sufficient for the heat cycling and impulse test laboratory. Corresponding clearance from prohibition zone to the barrier is found out to be 200 mm from table 7.1. Individual fences are provided for each test area. This is done so that each test area can be accessed independently irrespective of if they are running or not. Control wire the testing voltage transformer shall be run through theses fences in such a way that when the fences are opened it shutdowns the testing transformer. It would be impossible to start the test without closing all the fences.

Alternating test voltage 50/60 Hz (r.m.s. value)		Lightning impulse voltage 1,2/50 µs (peak value)	
U kV	s mm	U kV	s mm
≤1	no contact	20	100
3	20	40	175
5	30	60	250
6	35	80	325
10	60	100	400
15	85	150	550
20	115	200	700
25	140	250	850
30	170	300	1000
35	195	350	1100
40	225	400	1200
45	250	450	1300
50	280	500	1400
55	305	600	1650
60	335	700	1950
70	390	800	2200
80	450	900	2450
90	510	1000	2700
100	560	1100	2950
110	620	1200	3250
130	740	1300	3500
150	860	1400	3750
170	980	1500	4000
190	1100		
210	1240		
220	1300		
260	1550		
300	1850		
340	2150		
380	2450		
420	2750		
460	3100		
500	3500		
600	4500		
700	5600		
800	6900		
900	8300		
1000	9900		

Table 7.2 Prohibition zone dependent on test voltages to earth [7]

The prohibition zone for Impulse voltage generator shall be 1200 mm long since the peak test voltage to earth is rated to be 400 kV and that for heat cycling equipment shall be 288 mm linearly extrapolating voltage value corresponding to 52 kV since maximum test voltage is 52 kV. However a distance value of 305 mm chosen, which corresponds to the next highest voltage 55kV. It is to be noted that linear extrapolation beyond the highest specified values is not permissible [7]. When a solid barrier is used for example a solid wall the distance s mentioned in the above table need only be more than the half the value. However in the event of a voltage flashover to the solid barrier care should be taken that no hazard occurs due to the formation of parasitic voltages.

7.3.1 Calculation of required space for test area

Following data is available about the dimensions and voltages from manufacturers. Using this data and table 7.1 and 7.2 the area of test place can be calculated.

Floor area of impulse voltage generator = 193x124,5 cm^2

Floor area of capacitive voltage divider for measuring the impulse voltage = 79,5x89 cm^2

Floor area of high voltage transformer for heating cycle test = 30,5x53,3 cm^2

Floor area of regulating transformer of high voltage transformer = 63,6x67,2 cm^2

Floor area of heating transformer for heating cycle test = 70x100 cm^2

Floor area of regulating transformer of heating transformer = 70x70 cm^2

Floor area of tank = 400x150 cm^2 (This dimension is chosen to accommodate 8 meters of cable including a joint an indoor termination and outdoor termination.)

In addition to the above mentioned dimensions for testing and measuring equipments there shall be area dedicated for the control monitoring equipment. These shall be located in a separate room outside of the test area for safety reasons.

Floor area of control cabinet for impulse test = 105x105,5 cm^2

Floor area of control desk for heat cycling test = 160x80 cm^2

The tallest point with highest voltage among all the equipments is the impulse voltage generator which has a height of 198 cm. So the height of ceiling shall be at least 198 + 120 = 318 cm. Fig. 7.1 shows one possible arrangement for single impulse test and heating cycle test device. However it shall be noted that in practice the space required shall vary depending upon the room available for testing and the practicalities related to the preparing the cable for testing (Larger size cables area difficult to maneuver). There is one layout with two heating cycle devices and one impulse voltage device for future expansion.

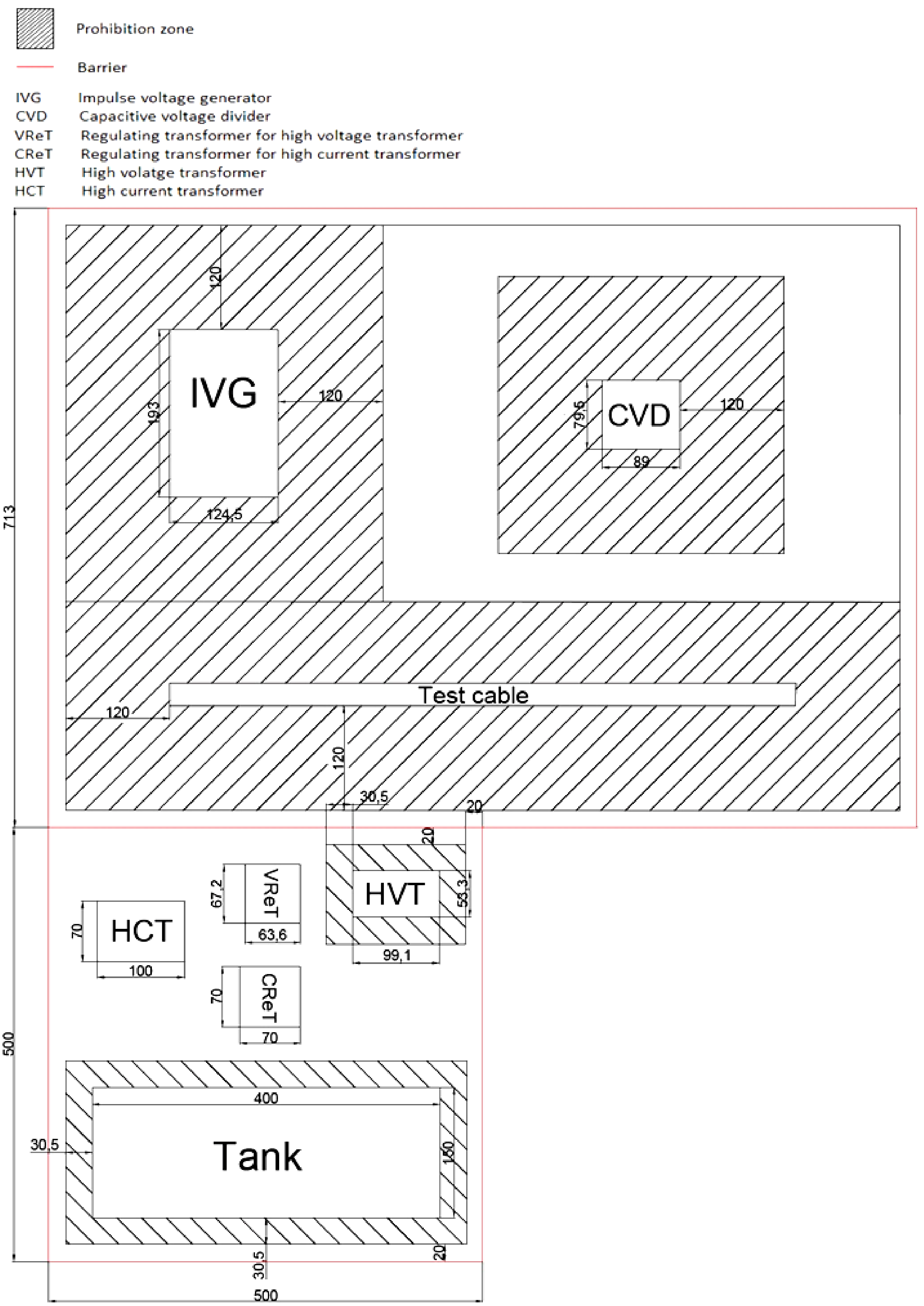


Fig. 7.1 - Proposed test area plan

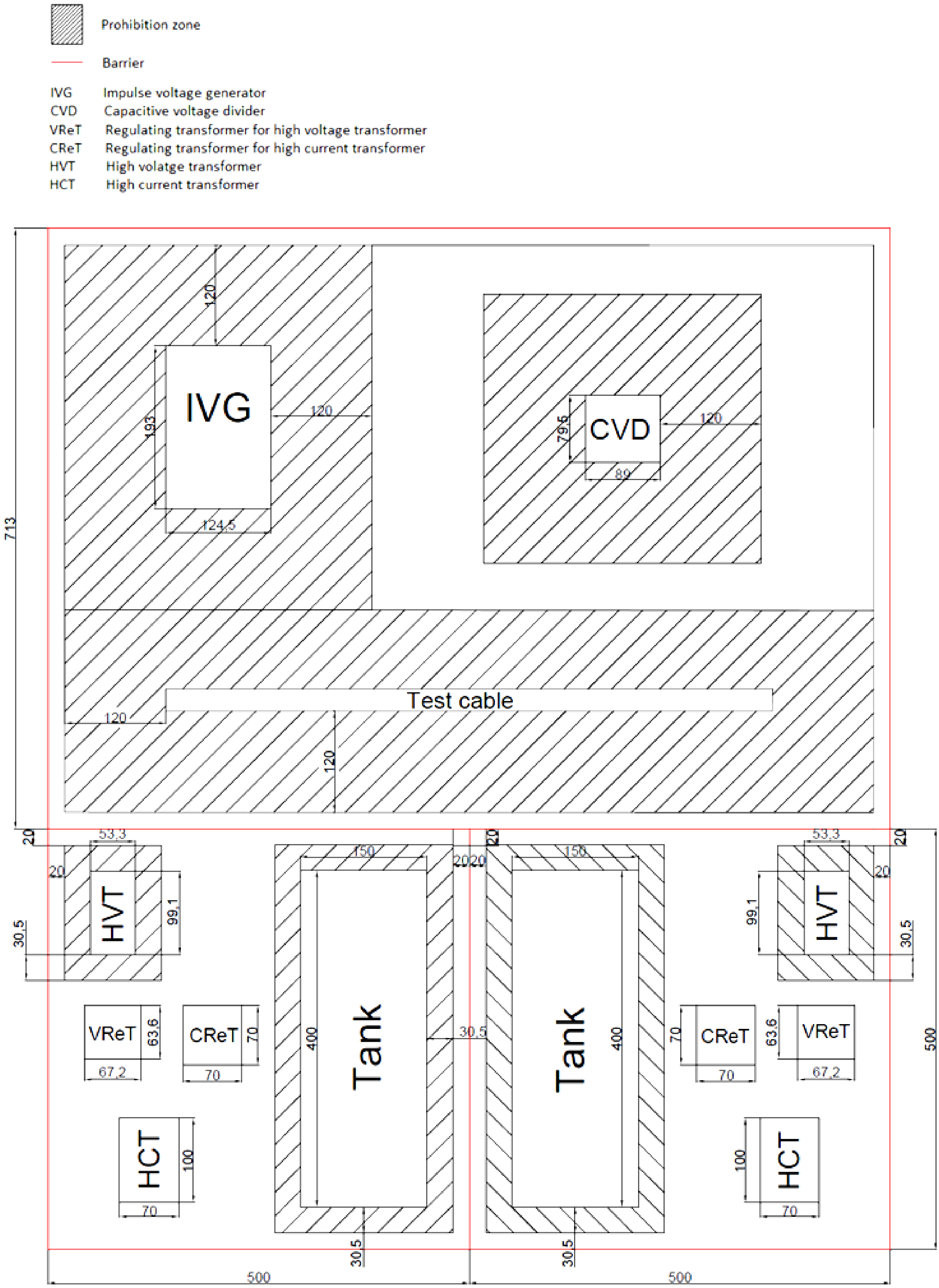


Fig. 7.2 - Proposed test area plan for future expansion

8. Additional test

8.1 Humidity and salt fog tests

Heating cycle tests gives a good estimate in terms of the thermal performance of the cable accessories in service conditions however it does not provide any information about how it would react to a corrosive and deteriorating environment. Standard way to evaluate this would be by conducting humidity and salt fog tests. Voltage source for testing is already available in Ensto Finland Oy's laboratory and it is only the test chamber that needs to be built up.

8.1.1 Test specification

The voltage sources used can be either three phase AC or single phase AC. The maximum voltage drop at the high voltage side of the source shall be less than 5 % at 250 mA leakage current during the test [1]. I suggest using the single phase AC transformer at Ensto Finland Oy's facility as the source since it meets the requirements.

The test chamber used for the humidity and salt fog test shall be equipped with spray nozzles capable of discharging atomized water at a rate of 0,4 ± 0,1 litre/hour/m3. The conductivity of the spray water shall be 70 ± 10 mS/m for humidity test and 1600 ± 200 mS/m for salt fog tests [1]. The design of the tank shall be such that water should not reach the accessories other than from the spray nozzle or humidifier.

8.1.1.1 Test chamber [1]

Test chamber shall have adequate dimensions to accommodate all the accessories under test. Chamber dimensions shall be decided taking into consideration the size of the accessory, test voltages, safety clearances, stray electric fields and the number of spray producing nozzles. It should be constructed from corrosion resistant, waterproof materials. All high voltage bushings and support insulators should be mounted on earthed supports to ensure that an electric field does not exist along the surface of the chamber. There shall be observation windows provided to track the progress of the test. The supply shall be brought to the chamber through appropriate bushings. These bushings shall be designed with a long creepage length to resist flashover. The test chamber may be ventilated to prevent a build-up of pressure inside, but any such ventilation should not allow a significant amount of vapour or fog to escape to the atmosphere. For the humidity and salt fog tests, the rate of flow of solution into the atomizing sprays shall be measured and monitored. There shall be drainage system provided to drain away the water from the chamber. The figure below shows Enato’s products undergoing salt fog test in Veiki-VNL test laboratories in Hungary.

Fig. 8.1 – Salt fog test

8.1.1.2 Spray equipment for humidity and salt fog tests [1]

The spray equipment shall be arranged so that it fills test chamber and circulate among all the accessories naturally. It shall never blow fog directly on to the test object. It shall be made sure that at least 80 % of the water ejected by the nozzles should be atomized into droplets not greater than 10 µm in diameter.

8.1.1.3 High voltage transformers [1]

Single-phase transformers should be star-connected with the neutral point earthed. The voltage in the test circuit shall remain stable and should not vary much owing to the varying leakage currents (voltage drop at the high voltage side of the source shall be less than 5 % at 250 mA leakage current during the test). The output voltage of the transformer shall be measured and it shall be also possible to control this voltage.

8.1.2 Installation [1]

The test accessories shall be installed in the humidity chamber with the accessories having the same orientation and relative spacing as installed in service, and according to manufacturer's instructions. For the protection of the transformer leakage current is measured and the transformer is de-energized the when a leakage current of 1,0 ± 0,1 A r.m.s. flows in the high-voltage circuit for a period between 50 ms and 250 ms.

8.1.3 Test procedure

The humidity chamber during the tests shall be at ambient temperature .Before the test begins the test object shall be photographed from front and back. Similar photographs shall be taken when the test is finished. Photographs shall show clearly the condition of the leakage path. The condition of the samples shall be noted at the end of the test. The test results shall record the occurrence of any flashover, a description and photographs of the condition of the accessories. Test object shall not be interfered with once the test has begun or during the test. It is not allowed to clean the accessories after the test has begun. Voltage used for testing shall be 1,25 times the nominal voltage and test duration shall be 1000 hours [2].

8.1.4 Requirements [2]

No breakdown or flashover shall take place, no more than 3 trips are allowed and there shall be no substantial damage to the test samples such that the performances of the accessories have deteriorated considerably. Test samples shall maintain their dielectric quality all throughout the test. The erosion to a depth shall be limited to 2 mm or 50 %, whichever is the smaller, of the wall thickness of the insulating material. No splitting or puncture of the material accessory shall be allowed.

9. General organization of the test facility

9.1 Control room

There shall be separate control rooms provided for different test areas. All controlling and monitoring equipment shall be located here. It should be possible to clearly observe the test area from the control room. The control room should have enough space for the personnel and equipment.

There shall be adequate lighting provided for observing the test without any difficulties. Some test might require the control room to have less or more light so it is advisable to have lamps whose intensities can be varied. The lamps shall be arranged in such a way that it does not cause reflections on to the windows which might obscure the view to the test area.

It is desired to have the power supply which is free of disturbance from the outside environment. Air conditioning shall be provided for the comfort of the personnel in the control room. However it should be noted that the humidity of the room should not exceed 60%, which can cause harm to the sensitive equipments in the room [17].

9.2 Electromagnetic shielding

Most of the modern high voltage labs are provided with electromagnetic shielding to prevent external disturbances from affecting the accuracy of the measurement system. This can be achieved by covering the inside walls and ceiling of the test room with steel sheaths [18]. The floor shall be covered with copper network which also serves as ground return. All of these shall be interconnected at regular intervals. All the doors shall also be connected with the steel walls [17]. Where there are windows they shall have metallic mesh for screening purpose [17]. All the supply cables shall be shielded too. This can be achieved by using metal tubing around the conductors.

9.3 Earth return

There are two options suitable for the earth return system. One is to use metal plates as earth return and second option is to use a grid of copper wires embedded in the concrete [19]. Second option even though less efficient than the first one is the method I suggest to use in our particular case, because it is less expensive. This grid Access to the metal grid is made by a number of tapings distributed on the test area [19]. Copper is preferred over aluminium for making the grid because copper is more resistant to corrosion than aluminium.

9.4 Air conditioning

Ideally the test area should be maintained within the limits of temperature, humidity and pressure as mentioned in the standard. In additions to this the air should be free from dust and other foreign matter. There shall be stratification of temperatures allowed and the air speed shall be modest. So the air conditioning system shall be designed considering all the above factors in mind.

9.5 Overhead cranes, lighting, drainage and assembly room

These are required to move the test objects and some of the test devices if necessary. It would be ideal to have 2 different speeds (slow and fast) for the crane. Nylon ropes can be used to attach the crane to test objects to provide isolation. There shall adequate lighting provided in the test area. The test setup is usually photographed for reference so in this point of view also the lighting points should be arranged in such a way to get decent pictures of test setup. There would be wet tests carried out in the laboratory which calls for an efficient drainage system. The floor shall have slope between 0,5 to 1 cm/m towards the outlet to drain the water effectively [17]. The water tanks for wet testing shall be connected to drainage pipes so it can be drained if desired. There shall be an assembly room close to the test area, where the cable for testing can be prepared and all the cable accessories can be assembled on the cable.

10. Results and conclusion

Standards IEC 61442 and EN50393 respectively were carefully studied to understand the testing procedure and requirement of the testing equipments. Specifications of the test equipments for heating cycle test were found out by carrying out tests in Ensto Finland Oy's own laboratory. Technical specifications are given in the appendix. Based on the results prices were enquired from various manufacturers for all the test equipments. Devices were chosen based on their price and how well they matched our requirement. The companies with which Ensto Finland Oy had done business were given more preference. Following are specifications for the test devices.

Heating cycle test:

Heating transformer minimum current requirement = 800A

Heating transformer voltage output = 12,5V

High voltage transformer minimum current requirement = 357A

High voltage transformer minimum voltage requirement = 52 kV

Impulse voltage test:

Impulse voltage test set peak voltage = 400 kV

Test place for one heating cycle and one impulse test system:

Minimum area required for testing = 120 m^2

Minimum height of the ceiling = 3.18 m

Test place for two heating cycle and one impulse test system:

Minimum area required for testing = 96 m^2

Minimum height of the ceiling = 3.18 m

11. References

[1] IEC 61442, Second edition, 2005-03, Test methods for accessories for power cables with rated voltages from 3,6/6(7,2) kV up to 20,8/36 (42) kV

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Appendix A

Impulse voltage testing system specification

General specification	
Manufacturer	Himalayal Corporation Limited
Product code	HIVG 400-20
Rated output voltage	±400 kV
Rated energy output	20kJ
Number of stage	4
Maximum charging voltage per stage:	±100kV
Stage energy	5kJ
Impulse capacitance per stage	1µF
Impulse Voltage Divider	
Rated voltage	400kV
Rated capacitance	400pF
Voltage ratio	1000:01:00
DC Charging apparatus	
Input voltage	220V ±10%
Frequency	50/60Hz
Fully charged voltage	100kV

Impulse voltage testing system component list

HIVG 400-20 Impulse Voltage Generator	1 set
Impulse Voltage Divider	1 set
Charging Apparatus 100kV 20mA	1 set
Digit Control System	1 set
Digit Measuring System	1 set
Measuring and control cables	1 set

Appendix B

Heating cycle testing system specification

High voltage transformer	
Manufacturer	Hipotronics Inc
Type	760 - 40
Input Voltage	380V, single phase, 50Hz
Power rating	40 kVA
Maximum output voltage	60 kV
Continuous output current	500 mA
Output current range	10 - 100% of rated current
Output voltage range	10 - 100% of rated voltage
Duty Cycle	40kVA 1 hr. ON, 1 hr. OFF/Continuous @ 30kVA
Output Connection	Epoxy Output Bushing
Metering	Digital, 1% of FS, for 10-100% of system output
Control / Regulator Weights	363kg
High current transformer	
Manufacturer	Hipotronics Inc
Type	LV - 12,5
Output Voltage	12,5 V
Output Current	2000 A
Temperature Meter Range	0 - 199.9 C^{o}
Temperature Meter Accuracy	±1% for 10 - 90% of meter range
Temperature Thermocouple	Type k (optically isolated)
Regulator Voltmeter Range	0 - 1000V AC
Regulator Voltmeter Accuracy	±2%
Regulator Output Current Range	0 - 20 A
Regulator Current Meter Accuracy	±2%

Appendix c

Cable specification

PRYSMIAN CABLES & SYSTEMS

AHXCMK-WTC 3-core EN

Product name			AHXCMK-WTC 3x50Al/16Cu 20 kV	AHXCMK-WTC 3x95Al/16Cu 20 kV	AHXCMK-WTC 3x150Al/25Cu 20 kV	AHXCMK-WTC 3x240Al/25Cu 20 kV
EAN-code		**64 100+**	**06 242 60-3**	**06 242 62-7**	**06 242 64-1**	**06 242 66-5**
Customs code			85 44 60 90			
CONSTRUCTION DATA						
Diameter over conductor (1)		mm	8.0	11.3	14.1	18.1
Diameter over cable (diameter of a circle drawn around the cable) (1)		mm	54	62	68	78
Weight (1)	aluminium	kg/km	370	750	1165	1925
	copper	kg/km	185	150	215	215
	cable	kg/km	1800	2550	3250	4500
DELIVERY DATA						
Standard delivery length		m	500	500	500	500
Standard delivery drum			K22	K24	K24	K26
Weight (1)	cable+drum	kg	1310	1725	2075	3150
MECHANICAL DATA (2)						
Minimum permissible bending radius during laying		m	0.65	0.75	0.82	0.94
Minimum permissible bending radius at final installation (3)		m	0.46	0.53	0.57	0.66
Maximum permissible pulling force with a pulling grip		kN	2.2	4.2	6.7	8.5
Maximum permissible pulling force with a pulling eye		kN	7.5	14.2	20.0	20.0
ELECTRICAL DATA (2)						
Maximum DC resistance of phase conductor	conductor 20°C	Ω/km	0.641	0.320	0.206	0.125
AC resistance of phase conductor (1)	conductor 65°C	Ω/km	0.76	0.38	0.25	0.15
	conductor 90°C	Ω/km	0.83	0.42	0.27	0.16
DC resistance of metallic screen, max	metallic screen 20°C	Ω/km	1.2	1.2	0.8	0.8
Inductance (1)		mH/km	0.38	0.34	0.32	0.30
Operating capacitance (1)		μF/km	0.17	0.21	0.24	0.30
Charging current (1)	at 20 kV	A/km	0.6	0.8	0.9	1.1
Earth fault current (1)	at 20 kV	A/km	1.8	2.3	2.6	3.2
CURRENT RATINGS (2)						
In air	conductor 65°C	A	130	190	250	330
	conductor 90°C	A	160	230	305	400
In ground	conductor 65°C	A	145	205	260	340
SHORT CIRCUIT CURRENTS (2)						
Maximum permissible short circuit current for 1 second	phase conductor (4)	kA	4.7	8.9	14.1	22.6
	metallic screen (5)	kA	2.3	2.3	3.4	3.4

(1) Approximate value
(2) See the basic assumptions at general information of products.
(3) Final installation with careful single bending.
(4) Initial temperature of conductor before short circuit 90 °C, final temperature of conductor after short circuit 250 °C.
(5) Initial temperature of metallic screen before short circuit 85 °C, final temperature of metallic screen after short circuit 250 °C.